Event Data Recorder Use in Traffic Crash Reconstruction
Level 1
Generic Data Analysis DeltaV

This Training Developed By:
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Generic Data Analysis
A different way to think of EDR Data Analysis Independent of Manufacturer, or Model or Model Year

ITS JUST DATA
Where You Get the Data: An EDR Report

EDR Reports May Contain Two **Types** of Crash Data

- **Pre-Crash Data**
  - Speed
  - Throttle or Accelerator Pedal
  - Brake on/off
  - Steering, Yaw Rate, Stability Control info & more

- **Delta V – Crash Pulse Data**
  - Longitudinal (X-axis) Crash Pulse or DeltaV
  - Lateral (Y-axis) Crash Pulse or DeltaV
Generic Data Analysis

• We will discuss DeltaV data First
• We will discuss it from a “generic” perspective
• Remember - ITS JUST DATA – no matter what kind of car it comes from.
DeltaV

- We know that the Greek letter $\Delta$ (Delta) means change.
- "V" is an abbreviation for velocity (in a vector sense).
- Combining the two we see that DeltaV expresses a change in velocity during a collision.
- DeltaV is a way to describe the seriousness of a crash.
- Usually written as $\Delta V$. 
Crash Pulse

- Average crash pulse lasts 100ms to 150ms
- There are 1000ms in each second
- So... a 100ms crash pulse lasts 1/10th of a second

Can be as short as 60 ms (body on frame type vehicle (stiff) into barrier (does not deform))
Can be longer than 300 ms (sideswipe)
Cumulative DeltaV Equals the Area Under the g vs. t Crash Pulse Curve

We seek to find the “Area Under this Crash Pulse Curve” by breaking it in to small rectangles, then adding all of incremental rectangle areas.
DeltaV as “Area Under Curve”

If we choose small enough time increments (width) for each of our rectangles, then add the area of all the rectangles together we have a good estimate of the total “Area Under the Curve”

Q: Why?

A: The area under the acceleration vs. time curve is the total DeltaV experienced in the crash pulse
DeltaV as “Area Under Curve”

- Check the units on the graph:
- The units on the vertical axis are g’s.
- G-Units are converted to fps by multiplying by 32.2
- The units on the horizontal axis are milliseconds or thousandths of a second
- So... when we multiply fps/second x seconds we get fps or change in speed (in units of fps).
- To convert to DeltaV in mph just divide by 1.466
- Repeating: The area under the acceleration vs. time curve is the total DeltaV experienced in the crash pulse
Was the entire crash captured? – How do you know?

Yes Completely captured – g values return to (near) Zero

Cumulative DeltaV Equals the Area Under the g vs. t Crash Pulse Curve

Area Under the Curve Example - Chrysler

Crash Pulse Acceleration Data

Longitudinal Crash Pulse (Most B)
Crash Pulse Acceleration and Cumulative DeltaV Data from a Ford. Two curves on one graph.

Yes, the entire crash was captured? – How do you know?

1. g values return to (near) zero
2. Cum DeltaV Curve comes parallel to X Axis
Cumulative DeltaV Equals the Area Under the g vs. t Crash Pulse Curve
Ford 03 CVic Crash Pulse and Cumulative Delta V Data

Was the entire crash captured? – Maybe….. Maybe Not

Crash Data NOT Completely captured

g Data headed toward Zero but not there yet

Cum DeltaV Data not Parallel to X-Axis

So we can say that the DeltaV is at least this much, but we do not know how much.
Cumulative \( \Delta V \) Equals the Area Under the \( g \) vs. \( t \) Crash Pulse Curve

G values return to Zero – Crash Over

One More Example 2013 GM Product
For GM Cumulative DeltaV graph is presented on a different page of the CDR report.

DeltaV curve comes parallel to X-Axis → Crash Over

Cum DeltaV Data
DeltaV Accuracy

• We note that the ACMs ability to calculate DeltaV as the “area under the crash pulse curve” is not perfect.

• Research indicates that... DeltaV “Accuracy is +/-10%”
• This value is generally accepted.
• So... we introduce a new term – “Nominal DeltaV”
• The Nominal DeltaV is the DeltaV as reported in the CDR Report.
• And, this +/- 10% accuracy range around the Nominal DeltaV value should be considered in any calculation that uses DeltaV.
DeltaV – Simple Inline Examples

- A vehicle traveling 60 mph (100 kph) strikes a similar parked vehicle. The cars stick together and depart at 30 mph (50 kph). What is the DeltaV for the vehicles?

\[ \text{DeltaV} = \text{Post Crash Velocity} - \text{Pre Crash Velocity} \]

**Bullet DeltaV**
- 60 mph (100 kph) minus 60 mph (100 kph) = 0 mph (0 kph)
- 30 mph (50 kph) minus 0 mph (0 kph) = +30 mph (50 kph)

**Target DeltaV**
- 30 mph (50 kph) minus 0 mph (0 kph) = +30 mph (50 kph)
- 50 mph (50 kph) minus 0 mph (0 kph) = +50 mph (50 kph)

Equation 7
DeltaV an Example (Restitution Intro)

- NCAP 35 mph full barrier collision (56 kph) (15.6 m/s)
- (Click to Play)
- Approach Velocity is 35 mph (56 kph) (15.6 m/s)
- Q: What is Final Velocity?
  - A: Approximately -4 mph (-5.6 kph) (1.56 m/s)
- Q: Why does it bounce back?
Answer - Restitution

- Elastic
- Plastic
Example Collisions – Restitution Considerations

• 40 MPH Barrier End Central Collision (64 kph)

• 40 MPH Barrier End Offset Collision (64 kph)
Calculating Restitution ($e$)

\[ e = \frac{\text{Separation Speed}}{\text{Closing Speed}} \]

- Separation Speed = Speed V4 – Speed V3
- Closing Speed = Speed V1 – Speed V2

**Restitution**

- Large Collisions trend toward Plastic ($e = 0$)
- Small Collisions trend toward Elastic ($e = 1$)
DeltaV – Simple Inline Examples With Restitution

• The DeltaV for a vehicle that strikes a tree and bounces straight back is easy to calculate.
• Approach Velocity = 40 mph (64 kph) (18 m/s)
• Departure Velocity = -3 mph (-5 kph) (-1.3 m/s)

• Calculate the DeltaV

• \( \text{DeltaV} = \text{Post Crash Velocity} - \text{Pre Crash Velocity} \)  

• \( \text{DeltaV} = -3 - (40) = -43 \text{ mph} \) (-69 kph) (-19.2 m/s)

A DeltaV of -43 mph is very different from a DeltaV of (positive) 43 mph

The Signs are Important
Example Collision – Restitution Considerations

• IIHS 40 mph 40% offset barrier collision (64 kph)
• (Click to play)
• Approach velocity is 40 mph (64 kph) (18 m/s)
• Departure velocity is -4 mph (-6.4 kph) (-1.8 m/s)
• Calculate The Coefficient of Restitution (COR)

\[
e = \frac{\text{Separation Speed}}{\text{Closing Speed}}
\]

\[
e = \frac{4}{40}
\]

\[
e = 0.1 \text{ or } 10\%
\]

Note: Separation and Closing Speeds will always be positive numbers. COR \((e)\) will also always be positive.
Example Low Speed Collision – With Restitution

- Low Speed Crash
- (Click to play)
- Closing Speed is 9.4 mph (15.1 kph) (4.2 m/s)
- Separation Speed is 3.6 mph (5.8 kph) (1.6 m/s)

\[ e = \frac{\text{Separation Speed}}{\text{Closing Speed}} \]

\[ e = \frac{3.6}{9.4} \]

\[ e = 0.38 \text{ or } 38\% \]

Compare this calculated Low-Closing-Speed COR of 0.38 (38%) to the previous High-Closing-Speed 40 mph crash that had a COR of 0.1 (10%). We repeat:
- Large Collisions trend toward Plastic \((e = 0)\)
- Small Collisions trend toward Elastic \((e = 1)\)
Where does the restitution take place?

So... The reported Cumulative DeltaV includes speed change from both crash forces AND restitution forces.
DeltaV – Inline w/ Restitution

- A vehicle traveling 60 mph (100 kph) strikes a similar parked vehicle. The collision has a restitution coefficient of 10%. Use the stated speeds below to calculate the closing and separation speeds.

\[
V_e = \frac{V_3 - V_4}{V_2 - V_1}
\]

Closing Speed = 60 mph, Separation Speed = 6 mph

\[
e = \frac{33 - 27}{0 - 60} = \frac{6}{60} = 0.1
\]

Closing Speed = 100 kph

Separation Speed = 10 kph
Figure 1: Occupant Maximum Injury as a function of Longitudinal Delta-V.
DeltaV – Injury Tolerances

A DV of 10 mph has a probability of AIS 3+ injury of 2%

A DV of 40 mph has a probability of AIS 3+ injury of 75%

Let's look at some belted airbag restrained Examples

**Figure 1:** Occupant Maximum Injury as a Function of Longitudinal Delta-V.
Yes, we all know seatbelts and airbags are good ideas.

We see that an unbelted DV of 40 mph has a probability of AIS 3+ injury of more than 95%.

**Figure 1:** Occupant Maximum Injury as a Function of Longitudinal Delta-V.
DeltaV – Injury Tolerances

- General rules * for a healthy properly restrained front seat occupant in a modern car:
  - 5g Crash Pulse or 5 mph $\Delta V$ – Very low probability of injury (8 kph)
  - 10g Crash Pulse or 10 mph $\Delta V$ – Airbags may deploy (16 kph)
  - 20g Crash Pulse or 20 mph $\Delta V$ – Serious injury possible (32 kph)
  - 40g Crash Pulse or 40 mph $\Delta V$ – Serious injury likely, some fatals (64 kph)
  - 60g Crash Pulse or 60 mph $\Delta V$ – Fatality more likely than not (97 kph)

- Remember … acceleration is defined as $\frac{\Delta V}{\Delta t}$

- So DeltaV is just an indicator of the severity of the crash

- Notice $\Delta V$ is not an acceleration, we know nothing about $\Delta t$, or the duration of the crash

* Look for exceptions in DeltaV Injury correlation in your crash. Exceptions: Belt Usage, Under/Oversize, Frail, Elderly, Pre Existing Conditions, Out of Position, Vehicle Design...
Uses of Delta V

- Biomechanics use it for injury potential
- Recons use it to get speed at impact
- It must be combined with other scene evidence to get speed at impact – like postcrash travel or weights
- Since forces in a crash are equal and opposite, in a two car collision, can use an EDR in the victim’s vehicle to get to speed at impact in perpetrator’s vehicle.
Using Delta V

- First we learn the equations we can use it in.
- Then we learn where in the EDR report to find the Delta V, and practice using it.
- Then we learn if we can use the numbers as we found them or if we need to adjust them for any special circumstances.
Speed at Impact from Delta V – Tools for your toolbag

• Inline – Delta V + postcrash
• Inline – Closing speed (uses inv. prop DV)
• Angled Departure – Delta V + Cos Θ postcrash
• 90 Degree Intersection – Inline approx. CS
• Effective mass ratio adjustments closing speed
• Angular – triangular velocity vectors
  (uses inv. Prop DV + postcrash)
Example Problem - Relating $\Delta V_1$ to $\Delta V_2$

Newton's laws tell us forces in a crash are equal and opposite. DeltaV is inversely proportional to weight

- Use the DeltaV of a vehicle with an EDR to get DeltaV of another vehicle without an EDR (This is **Important!!**).
- A loaded tractor trailer was slowing for a stop sign. The driver was unable to stop and struck a stationary car that had already stopped in front of it. The car was equipped with an EDR that recorded a DeltaV of +27.2 mph (43.8 kph) (12.1 m/s)
- What was the DeltaV for the bullet tractor trailer?
- Weights
  - Tractor Trailer = 42000 lbs (19000Kg)
  - Car = 3480 lbs (1580 Kg)
Inversely Proportional DeltaVs - Example Problem

\[ \Delta V_1 = - \Delta V_2 \frac{W_2}{W_1} \]  

\[ \Delta V_1 = -(+27.2) \text{mph} \frac{3480}{42000} \]

\[ \Delta V_1 = -27.2 \text{mph (0.0828)} \]

\[ \Delta V_1 = -2.2 \text{mph} \]

\[ \Delta V_{\text{Truck}} = -2.2 \text{mph} \]

\[ \Delta V_{\text{Car}} = +27.2 \text{mph} \]

- The weights and the DeltaV for \( V_2 \) was given in the problem statement.
- This solution is calculated with Equation 12
- This calculation indicates that the DeltaV for this bullet truck was -2.2 mph (-3.5 kph). How does this compare with the car’s EDR documented DeltaV of 27.2 mph (43.8 kph).
- Which vehicle would you choose to be in?
- Use caution when using a heavy vehicle to estimate the Delta V of a light vehicle – the calculation is very sensitive to small changes in the light vehicle’s weight.
DeltaV – Example Application

\[ \Delta V_1 = -\Delta V_2 \frac{W_2}{W_1} \]  

Equation 12

• Purpose/Use of Equation: If you know one vehicle’s DeltaV and the vehicle weights in a two car collision, you can calculate the other vehicle’s DeltaV. This is ENORMOUSLY useful, it’s an intermediate step to getting to speed at impact.

• This is just another application of Newton’s 2\textsuperscript{nd} and 3\textsuperscript{rd} laws

• \textit{GO TO WORKSHEET – INVERSELY PROPORTIONAL DELTA V}
  Page 3-65
New Topic: Inline Speed at Impact from Longitudinal DeltaV and Post Crash Speed

\[
\text{Speed at Impact} = \text{Post Crash Speed} - \Delta V_x \quad \text{Equation 7}
\]

\[V1 = V3 - \Delta V_x\]

For negative DV, minus a minus is like a plus

**Departure X** 20 mph (32 kph) \(\Delta V_x -10\) (16)

**Approach Velocity** 30 mph (48 kph)

**GO TO WORKSHEET:** INLINE DEPARTURE SPEED AT IMPACT (approximately page 3-67 for imperial units, 3-68 for metric units)
How to Read an EDR Report

– Open the Sunfire Inline Project 3-69; find page 3 (start of CDR file).
– Note there is a section halfway down the page “Data Limitations”
– Data Limitations are important and part of every CDR Report. They are written by the manufacturer, for your benefit, to help you to understand the details of the data they are presenting to you.
– Reading these is so important we have created an acronym to reinforce it, and added an F word for emphasis.
– We introduce the acronym RTFDL. RTFDL stands for **READ The Freaking Data Limitations**. You may substitute other F words of your own choosing.

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**Data Limitations**

**Recorded Crash Events:**

There are two types of Recorded Crash Events. The first is the Non-Deployment Event. A Non-Deployment Event records data but does not deploy the air bag(s). It contains Pre-Crash and Crash data. The SDM can store up to one Non-Deployment Event. This event may be overwritten by another Non-Deployment Event. This event will be cleared by the SDM, after approximately 250 ignition cycles. This event can be overwritten by a second Deployment Event, referred to as a Deployment Level Event, if the Non-Deployment Event is not locked. The data in the Non-Deployment Event file will be locked, if the Non-Deployment Event occurred within five seconds before a Deployment Event. A locked Non-Deployment Event cannot be overwritten or cleared by the SDM.

The second type of SDM recorded crash event is the Deployment Event. It also contains Pre-Crash and Crash data. The SDM can
If you have a question about a data element the Data Limitations are your first resource to answer your question.

- When you read an EDR file, you have a choice whether to read the data limitations when you encounter them on the first page, or to initially skip by them and come back to read them later, after you formulate your questions after looking at the data. Some people have a low retention rate if they don’t yet understand the significance of the information being presented, and get more out of it reading with the purpose of answering specific questions.

- For this, your first time, please read through the data limitations first, to get an idea of what type of information they contain. After your first time you may use your discretion as to when you read the data limitations.

- Open the video introducing the project – it will guide you through reading your first EDR file.
In the previous problem we used Equation 12 above to find the DeltaV of the non-EDR equipped vehicle.

We now introduce another important equation, #9, to allow us to use both of the DeltaV’s from two colliding vehicles to calculate Closing Speed.

\[ \text{Inline Closing Speed} = \left[ \frac{1}{1+e} \right] \left[ |\Delta V_1| + |\Delta V_2| \right] \]  

Equation 9
In this Equation

\[ e = \text{The Coefficient of Restitution} \]

Equation 9

\[ \begin{aligned}
\text{Closing Speed} &= \left[ \frac{1}{1 + e} \right] [|\Delta V_1| + |\Delta V_2|] \\
\end{aligned} \]

In this Equation

\[ e = \text{The Coefficient of Restitution} \]

\[ \begin{aligned}
\Delta V_1 &= \text{DeltaV for Vehicle #1} \\
|\Delta V_1| &= \text{Absolute Value of DeltaV1} \\
\Delta V_2 &= \text{DeltaV for Vehicle #2} \\
|\Delta V_2| &= \text{Absolute Value of DeltaV2} \\
\end{aligned} \]

Lets use Equation 12 then Equation 9 to Calculate closing speed
Inline Closing Speed – Example Problem

• A 4000 lb target \(1816 \text{ kg}\) is stopped at a red light when it is rear ended by a 3000 lb \(1362 \text{ kg}\) bullet. The EDR in the target measures a \(+20 \text{ mph (32 kph)}\) longitudinal DeltaV. Assume that the vehicles stick together after the crash. What is the closing speed?

• First since we know the DeltaV of the target vehicle and the vehicle weights we can use the inversely proportional DeltaV relationship to calculate the DeltaV for the target vehicle with Equation 12. 
Closing Speed – Example Problem

• First since we know the DeltaV of the target vehicle and the vehicle weights we can use the inversely proportional DeltaV relationship to calculate the DeltaV for the bullet vehicle with Equation 12.

\[
\Delta V_{\text{Bullet}} = -\Delta V_{\text{Target}} \frac{W_{\text{Target}}}{W_{\text{Bullet}}}
\]

\[
\Delta V_{\text{Bullet}} = -(20 \text{ mph}) \frac{4000}{3000}
\]

\[
\Delta V_{\text{Bullet}} = -(20 \text{ mph})(1.33)
\]

\[
\Delta V_{\text{Bullet}} = -26.6 \text{ mph}
\]

Equation 12

\[
\Delta V_{\text{Bullet}} = -(32.2 \text{ kph}) \frac{1816}{1362}
\]

\[
\Delta V_{\text{Bullet}} = -(32.2 \text{ kph})1.33
\]

\[
\Delta V_{\text{Bullet}} = -42.8 \text{ kph}
\]
• Now since this is a special case where the vehicles stick together, for THIS case **restitution \((e)\) equals zero**.

• Next we substitute our knowns into the closing speed equation and solve.

  Closing Speed \[= \left[ \frac{1}{1 + e} \right] \left[|\Delta V_1| + |\Delta V_2|\right] \]

  \[
  \text{Closing Speed} = \left[ \frac{1}{1 + 0} \right] \left[20 + |−26.6|\right]
  \]

  \[
  \text{Closing Speed} = [1] \left[20 + 26.6\right]
  \]

  \[
  \text{Closing Speed} = 46.6 \]

  \[
  \text{Closing Speed} = \left[ \frac{1}{1 + 0} \right] \left[32.2 + |−42.8kph|\right]
  \]

  \[
  \text{Closing Speed} = [1] \left[32.2 + 42.8kph\right]
  \]

  \[
  \text{Closing Speed} = 75kph
  \]
• In the previous step we calculated the closing speed
• Closing Speed\(_{(e=0)}\) = 46.6 mph \((75.0 \text{ kph})\)
• Next we observe that the target was stopped.

We use **equation 8C** to calculate the pre crash speed of the bullet vehicle

\[
\text{Speed } V1 = \text{Closing Speed } + V2 \quad (V2 \text{ can be negative if coming from opposite direction})
\]

Speed \(V1 = 46.6 + 0 \quad (75.0 + 0)\)

Speed \(V1 = 46.6 \text{ mph} \quad (75.0 \text{ kph})\)
Inline Closing Speed – Example Problem

- But what if we find the vehicles separated by a significant distance (e was not zero).
- Then the calculation changes.

Closing Speed = \left[ \frac{1}{1+e} \right] \left[ |\Delta V_1| + |\Delta V_2| \right]

Closing Speed = \left[ \frac{1}{1+.1} \right] \left[ 20 + |-26.6| \right]

Closing Speed = .91 \times 20 + 26.6

Closing Speed = 42.4 \text{ mph}

Closing Speed = \left[ \frac{1}{1+.1} \right] \left[ 32.2 + -42.8 \text{kph} \right]

Closing Speed = .91 \times 32.2 + 42.8 \text{kph}

Closing Speed = 68.1 \text{kph}
• And as before, since we know how fast the target was going (it was stopped), we can calculate actual speed from the closing speed

• Closing Speed \(_{(e=0.1)} = 42.4 \text{ mph} (68.1 \text{ kph})\)

• Next we observe that the target was stopped. We use **equation 8C** to calculate the pre crash speed of the bullet vehicle

  \[
  \text{Speed } V1 = \text{Closing Speed} + V2
  \]

  Speed \(V1 = 42.4 + 0\) \(= 68.1 \text{ kph} + 0\)

  Speed \(V1 = 42.4 \text{ mph} \)  \(= 68.1 \text{ kph}\)
Closing Speed – Example Problem

- We should also recalculate the closing speed with a +/- 10% **Nominal** DeltaV tolerance – More to come on **Nominal** DeltaV
Closing Speed – Example Application

• We will see that we can use the DeltaV from the “good guys” car to calculate the impact speed of the “bad guys” car

• *Recommended Practice*: Closing Speed Worksheet 3-77

• *Recommended Project* – Aveo Inline Closing Speed Problem [*with restitution*] (approx. 3-79)
New Problem Type
Longitudinal DeltaV\(_x\) and Angled Departure

Speed at Impact = \(|V_3| \cos(\beta) - \Delta V_x\)

Where:

\(\Delta V_x\) = The Longitudinal DeltaV of the Vehicle of Interest

\(|V_3|\) = The absolute value of the post crash speed of the Vehicle of Interest
from the square root of 30*d*f equation (or square root 2*a*d)

\(\beta\) = (Beta) The angle measured between the approach and departure of
the Vehicle of Interest. Beta can be between 0 and 360 degrees
Longitudinal DeltaV and Angled Departure

Equation 13

\[ \text{Speed at Impact} = |V_3| \cos(\beta) - \Delta V_x \]

A vehicle approaches in the X direction

Vehicle #1 is redirected at an angle \( \beta \)

It is struck by a vehicle approaching at an angle

Approach V2
Equation 13

The EDR senses a Longitudinal DeltaV for V1

\[ \Delta V_x \text{ and Angled Departure } \]

\[ \text{Speed at Impact} = |V_3| \cos(\beta) - \Delta V_x \]

Minus the EDR based DeltaV

This case we can say, that the component of the departure speed along the approach axis...
Longitudinal DeltaV and Angled Departure

Equation 13

Speed at Impact = $|V_3| \cos(\beta) - \Delta V_{x(Longitudinal-Component)}$

Longitudinal DeltaV

V3 Cos($\beta$)

V1 Approach Speed

Equals the pre-crash, or approach speed, of V1
Delta$V_x$ and Angled Departure

\[ \text{Speed at Impact} = |V_3| \cos(\beta) - \Delta V_x \]

Example Equation 13 Crash – Click to Play
Delta$V_x$ and Angled Departure

Speed at Impact = $|V_3| \cos(\beta) - \Delta V_x$
DeltaV – Example Application

- *Recommended Practice* – Angled Collision Worksheet 3-91
- *Recommended Project* – Prius Intersection Problem 3-93
90° intersection central collisions (limited application)

“inline approximation” 1

- Data recorder in V2 only
- Isolate X and Y axis on V2. First look at V2 DV_y only, ignore DV_x. Treat as an inline collision with V2 standing still.
- \( F = \text{weight} \), V1 DV_x = V2 DV_y
- Closing speed = V1 DV_x + V2 DV_y
- For V2 DV_y 20, V1 DV_x = 20, Closing speed = 40 = Impact Speed for V2 stopped

Will underestimate speed in offset collisions
90° intersection central collisions (limited application)

**“inline approximation” 2**

- Now Isolate on V2 \( DV_x = -8 \)
- Now assume V1 is standing still and getting T-boned by V2.
- \( V1 \text{ } DV_y = 8 \)
- Closing speed = \( V2 \text{ } DV_x + V1 \text{ } DV_y = 16 \)
- Since V1 stopped, V2 Impact Speed = 16

Will underestimate speed in offset collisions
**Principal Direction Of Force (PDOF)**

- In a CENTRAL collision, the PDOF is the direction the forces are coming FROM and is *constant* thru the crash.

- In an offset collision, the direction of forces is *changing* during the crash, but the average of all the forces, over the entire duration of the crash, is called the Principal Direction Of Force (PDOF).

In this class we will represent the angle as Theta (Θ).
Newton and Crash Forces

All Collisions involve the exchange of forces between vehicles

Newton tells us the magnitude of the force exchanged is equal (3rd Law)

Newton tells us that the direction of the exchanged force is opposite in direction (3rd Law)
Collision Forces

This is a 35 mph barrier collision (56 kph)

The car approaches at +35 mph (56 kph) and rebounds at – 4 mph (6.5 kph)

The DeltaV is -39mph (62.5 kph)

Q: What direction was the force applied to the car?
A: From front to rear

Q How do we describe the direction in terms of PDOF?
Describing PDOF Direction

The PDOF Clock

- Note, Angles measured from 0°-360 degrees can also be expressed as a negative angle when measured counterclockwise from zero degrees.
Using the PDOF Clock

- Using the PDOF Clock
- Draw your impact force as a vector. Start from outside the clock drawing the vector to the center of the clock. Draw an arrow head on the end of the PDOF Vector
Using the PDOF Clock

- In this case the PDOF angle is from 0 degrees (towards 180).
- Your Clock Direction for PDOF is read where the Force Vector crosses the clock face, in this case 12 o’clock.
Using the PDOF Clock

So, Applying this technique to the Crown Vic crash:
• It had an impact force directed from 12 o’clock
• The PDOF is 0 degrees
Approach
Initial Contact (First Touch)
Maximum Engagement
Exchange of Forces
Exchange of Forces

- Because the momentum comes from two different directions, the exchange of forces is at an angle.

- The total force or PDOF applied to the blue car is represented by the red vector.

- Recall
  - The total force or PDOF applied to the silver car is represented by the blue vector.
  - The forces are exactly equal in magnitude (pounds force).
  - The forces are exactly opposite in direction.
Exchange of Forces

Q: Is this a Central Crash?
A: No... Because both vehicles are in motion the forces miss the CG of both vehicles.

Q: Would we expect these vehicles to rotate?
A: Yes, Both vehicles rotate counter-clockwise
Example 2 Describe PDOF Angle

This is a an intersection collision
Assume an approach angle of 90 degrees
• What does the PDOF look like?

Click to Play

Lets Determine the angles on the PDOF Clock
The PT Cruiser:
- Had an impact force directed from 2 o’clock
- The PDOF is 60 degrees.
Using the PDOF Clock for the Other Vehicle

The other vehicle:
- Had an impact force directed from 11 O’clock
- The PDOF is 330 degrees (or -30 degrees).
Example 2 Describe PDOF Angle

Q: Is this a Central Crash?

A: No... the forces miss the CG of both vehicles. Both vehicles rotate after the crash.
PDOF Examples – Central Impact

- (Click to play)
PDOF Examples – Eccentric Impact

- (Click to play)
PDOF Examples
Very Eccentric Impact

- (Click to play)
Delta V and PDOF – Missing Pieces

- In both IIHS barrier crashes videos the Cars were driven straight into the barrier.
- Q: Why didn’t the car bounce straight backwards?
- (Click to View)
The Answer - PDOF

• A: during the collision the direction of the force applied to the car changed.
  – At the beginning of the collision the forces were straight backwards.
  – At the end of the collision the forces were directed nearly towards the center of the car.

• The sum of all these forces, over the entire duration of the crash, is called the principal direction of force (PDOF)
Finding **Total DeltaV** from **DeltaVx** and **PDOF**

- Many EDRs give us only $\Delta V_x$ (Longitudinal DeltaV)
- Equation 10 tells us we must divide $\Delta V_x$ by the cosine of the Principal Direction of Force (PDOF) represented by the Greek letter Theta ($\theta$) to get the total DeltaV
Finding *Total* DeltaV from DeltaV<sub>x</sub> – Example Problem 1

- An officer investigates a u-turn crash and images the bullet vehicle (SUV with sunroof). The EDR reports a **longitudinal DeltaV** of -32.3 mph (52.0 kph).
- The officer examines the vehicle and estimates the PDOF as **from** 30 degrees (**towards** 210 degrees).
- What is the **total DeltaV** for this bullet vehicle

\[
\Delta V_{Total} = \frac{|\Delta V_x|}{\cos(\Theta)}
\]

Equation 10
Finding **Total DeltaV** from **DeltaV<sub>x</sub>** and **PDOF**

- First we note that the estimated angle is 30 degrees, nowhere close to 90 or 270 degrees. We can proceed with the analysis.

\[
\Delta V_{Total} = \frac{|\Delta V_x|}{\cos(\Theta)}
\]

\[
\Delta V_{Total} = \frac{|-32.3|}{\cos 30}
\]

\[
\Delta V_{Total} = \frac{32.3}{.866} = \frac{52 \text{ kph}}{.866}
\]

\[
\Delta V_{Total} = 37.3 \text{ mph @ 30 degrees}
\]

(60.0 kph @ 30 degrees)
How do you get the PDOF??

• From examining the crush profile
• Take the point on the vehicle near maximum intrusion and draw a line back to where that point started (for example, a headlamp or an edge of the hood).
• In *central collisions* it may also be perpendicular to the damage face
Resolving Delta V Into Components

The entire Delta V can be expressed as two Speed Changes that are added as vectors.

In this case we express those two parts based on our defined axis system.

We find a $\Delta V_x$ along the $X$ axis and a $\Delta V_y$ along the $Y$ axis.

Those parts are called components.
Newer EDR’s have BOTH X and Y $\Delta V$

The big triangle at left shows

- The Total DeltaV
- The Longitudinal DeltaV component along the X axis
- The Lateral DeltaV Component along the Y axis
Combining Components to Get Total

The total Delta V can be expressed as two Velocity Changes that are added as vectors. Pythagoras applies... The total DeltaV = the sum of the squares...

$$\Delta V^2 = \Delta V_x^2 + \Delta V_y^2$$

And... solved for total DeltaV

$$\Delta V = \sqrt{\Delta V_x^2 + \Delta V_y^2}$$

Equation 11
Combining Components to get Total DeltaV

Example Problem

A vehicle is involved in a collision where the EDR documents a Longitudinal DeltaV of \(-15\text{mph (24.1 kph)}\) and Lateral DeltaV of \(10\text{ mph (16.1 kph)}\). Find the magnitude of the total DeltaV.

\[
\begin{align*}
\text{TotalDelta} V &= \sqrt{\Delta V_x^2 + \Delta V_y^2} \\
\text{TotalDelta} V &= \sqrt{-15^2 + 10^2} \\
\text{TotalDelta} V &= \sqrt{225 + 100} \\
\text{TotalDelta} V &= \sqrt{325} \\
\text{TotalDelta} V &= 18.04 \text{ mph}
\end{align*}
\]

Equation 11

(29.03 kph)

Notably for this relationship to yield an accurate answer for Total DeltaV we must be sure that the module collected both a complete DeltaV_x, and a complete DeltaV_y.
Finding the PDOF Angle from $\text{Delta}V_x$ and $\text{Delta}V_y$²

• If we know two sides of a triangle we can calculate an angle

\[ \Theta = \tan^{-1}\left(\frac{\text{Delta}V_y}{\text{Delta}V_x}\right) \]

Equation 15

Note 1: We must be sure that the EDR captured all of the crash pulse (DeltaV) on both X and Y axis. Compare crash pulse durations.

Note 2: We see that theta and theta + 180 are both are solutions to this equation. This equation will always yield an angle that must be visually evaluated to see which solution is correct.
Finding PDOF Angle – Example Problem

A vehicle is involved in a collision where the EDR documents a Longitudinal DeltaV of +21mph (33.8 kph) and Lateral DeltaV of -12 mph (19.3 kph). Find the PDOF.

Note 1: First the investigator confirms that the EDR captured all of the crash pulse (DeltaV) on both X and Y axis by finding similar crash pulse durations in both cumulative DeltaV records.

The red PDOF indicates forces are from 150 degrees (and towards -30 degrees). When we take the inverse tangent of the Delta V’s, it gives us the direction the forces are TOWARDS.

\[ \Theta = \tan^{-1}\left(\frac{\Delta V_y}{\Delta V_x}\right) \]

\[ \Theta = \tan^{-1}\left(\frac{-12 \text{ mph}}{21 \text{ mph}}\right) \]

\[ \Theta = \tan^{-1}(-0.5714) \]

\[ \Theta \approx 150 \text{ Degrees} \]
DeltaV & PDOF Practice

- *Recommended Practice*: Calculating Total Delta V Worksheet (approximately page 3-105)
- Recommended Project – G6 PDOF Part 1 (Optional *demonstrate Part 1* rather than allowing the class to work it) [Click to Go] 3-117
- Instructor Optional – G6 PDOF **Part 2** (allowing the class to work it) 3-135
DeltaV Review

• Delta V is the area under the acceleration curve
• Forces in a crash are equal and opposite. Delta V is inversely proportional to weight. With Delta V from one vehicle, you can get the Delta V of the other vehicle if you know the weights.

\[ \Delta V_1 = -\Delta V_2 \frac{W_2}{W_1} \]  

Equation 12

• For Inline Crashes, adding the two Delta V’s yields closing speed

\[ \text{Closing Speed} = \left[ \frac{1}{1+e} \right] \left[ |\Delta V_1| + |\Delta V_2| \right] \]  

Equation 9

• For inline crashes, adding closing speed to the one vehicle’s speed gives you the other vehicle’s speed at impact

\[ \text{Speed V1} = \text{Closing Speed} + \text{Speed V2} \]  

Equation 8C
DeltaV Review

• For Inline Crashes, we can subtract Delta V from post impact speed to get impact speed.
  
  Speed at Impact = Post Crash Speed – Delta V_x  

  
  Equation 7

• For Angular Crashes, we must realize that Delta V is a Vector and Delta V’s at different angles can’t just be added or subtracted without using Trig.

• But if we know departure angle, we can still use post crash speed and Delta Vx to get impact speed

  Speed at Impact = \[ V_3 \cdot \cos(\beta) - \Delta V_x \]  

  
  Equation 13

• We can do A LOT MORE with angular crashes and Delta V but that requires more Trig
Cautions Using Delta V Information

1. Recorder only captures part of crash
2. Recorder captures data from BEFORE or AFTER crash
3. Missed Delta V before algorithm wake up
4. +offset in accelerometer (Toyota Gen 1 & 2)
5. Missed Delta V due to sensor clipping
6. *Is it an OFFSET collision where I need to make an effective mass ratio adjustment?*
7. *Do I need to consider GROUND FORCES*
8. Unusual DeltaV Curve Shape
9. *Part 563 EDR Regulations*
10. *Small Delta V’s*
Cautions Using \textit{Delta V} Information

1. Insufficient Duration

- Most crashes last 100 to 150 milliseconds, some barrier crashes and head-ons shorter, some pole, underride, angular, and sideswipe crashes longer.

\begin{itemize}
\item Typical Crash Duration up to 150ms
\item 01-04 Crown Vic 65ms typical after wakeup
\item Many early 2000’s Fords 116ms
\end{itemize}

- If the duration is not sufficient to capture the entire crash, the \textit{Delta V will be understated}. You can still use it but any speeds calculated from it must be considered a MINIMUM.
Cautions Using Delta V Information

1. Insufficient Duration

Classic example: 2001-2004 Crown Vic EDR were designed to capture only 50 ms after deployment, with typical deploy times in those days of 15ms in severe crashes, the resulting 65 ms was seldom enough to capture entire crash pulse.

Slope of Delta V line must become parallel to x axis or acceleration must settle to near zero to know entire crash has been captured.
Cautions using Delta V Information

2. **Excessive Duration**

2005-2011 Crown Vic, Grand Marquis, Town Car are the classic example with this issue.

- Crown Vic cumulative longitudinal Delta V register collects data as long as the algorithm runs – typical 300-400ms, worst case seen to date was 1900ms.

- Typical postcrash situation is vehicle skidding to a stop. Use decel rate from your postcrash skid analysis times duration, estimate how much extra Delta V is included in the EDR reported number.
Cautions Using Delta V Information

3. Missed ΔV Before wake up

- Generally NOT SIGNIFICANT in high Delta V frontals, the algorithm reaches the typical 1-2g wakeup within a few milliseconds.
- SIGNIFICANT in low Delta V events where 1-2G is a significant portion of the peak G’s. The tail missed can be estimated based on how sharp the onset of the crash is.
- Not all systems are “wake up” systems. There are “continuously running” systems like Ford Crown Vic that don’t have to wake up. These can sometimes be recognized by acceleration graphs that have data shown before time zero or where zero is the time of deployment.
Small percentage in big crashes

Missed Delta V Before Wakeup – Big Crashes
Missed Delta V before wakeup – small crashes
(Pre-563 or mfrs who kept low thresholds)
Cautions Using Delta V Information

4. +G offset in Delta V Calculation (Toyota)

- Toyota Gen 1 and some Gen 2 vehicles have + 0.39G offset in accelerometers
- Delta V calculated in frontal crashes will be under-reported, Delta V in rear crashes will be over reported
- Fixed midyear 2012 by Toyota in 3rd gen “12 EDR” for Part 563
- Not discussed in Data Limitations at this time. Test data in SAE 2013-01-1268 quantifies under and over reporting, corresponds to 0.4g in Gen 1. Test data in SAE 2016-01-1496 on 07 Yaris (Gen 2) indicates 0.87G. SAE 2016-01-1495 tests several vehicles, indicates it is vehicle dependent. Helps explain why Delta V may not correlate perfectly to scene evidence.
- Magnitude of a +0.39G offset on Delta V over 150 ms
  \[
  \frac{0.39 \text{g} \times (32.2 \text{fps/s}) \times (0.150 \text{seconds})}{1.466 \text{ (mph/fps)}} = 1.3 \text{mp}
  \]
  \[
  \frac{0.39 \text{g} \times (9.8 mps/s) \times (0.150 \text{sec})}{3.6 \text{kph/mps}} = 2.1 \text{kph}
  \]
Cautions Using Delta V Information

4. +G offset in Delta V Calculation (Toyota)
Cautions Using Delta V Information

5. Clipping

Sensor Clipping – always results in under-reporting

How a 40g Accelerometer would see this crash

Missed DeltaV
Cautions Using Delta V Information

5. Clipping

How do you identify it??
IF you have an acceleration graph, look for flat spotting at 40, 50, 60, 70, 80 or 100g. Many manufacturers use 50g accelerometers.
Identifying clipping

- A steady 50g produces 11 mph (17 kph) of speed change over 10ms (50G*32.2/1.466*0.01 sec) (50g*9.8*0.1)
- If your Delta V is over 35 mph (56kph), review the Delta V vs time data table. Subtract consecutive values to get the change over each 10 ms interval. Find the biggest one.
- 11 mph (17 kph) would indicate 50G over the entire 10ms (potentially clipped the entire time), 9mph (14 kph) would indicate spikes over 50G are likely, 7mph (11 kph) or less would indicate any spikes were only for a short time.
- Some ACM’s have over 50G accelerometers, this is only a diagnostic to identify possibility of clipping
Identifying Clipping from DV

Δ10 mph = 45G Avg
Δ12+ mph = 55+G Avg
Δ9+ mph = 40+G Avg

<table>
<thead>
<tr>
<th>mph</th>
<th>Delta-V (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-2.5</td>
</tr>
<tr>
<td>20</td>
<td>-5.6</td>
</tr>
<tr>
<td>30</td>
<td>-15.5</td>
</tr>
<tr>
<td>40</td>
<td>-28.0</td>
</tr>
<tr>
<td>50</td>
<td>-37.3</td>
</tr>
<tr>
<td>60</td>
<td>-44.1</td>
</tr>
</tbody>
</table>
FCA 2007 MY ACM Delta V from Acceleration Data

- Delta V in MPH, Accel in G's
- Time to airbag deployment in Seconds

NOT Clipping

20-30ms = 10 mph = 45avg

81G, No Clipping

100G Accelerometer Typical in FCA
Cautions Using Delta V Information
6. Eccentric or OFFSET collisions

• When using Delta V to calculate closing speed, if the offset is not considered, the closing speed will be under-estimated.
Q: What is the DeltaV Sensed by the trailer here at the kingpin?
A: 0 mph. An EDR here would miss 100% of the DeltaV.

Q: What is the DeltaV Sensed by the trailer here at the damage centroid?
A: DeltaV at the damage centroid is related to the weight of the car, the Delta V of the car, and the weight of the trailer. But how much of the trailer weight was involved in the crash?

A: Only part of it. And, the involved part of the weight is related to the eccentricity, or the measure “h” and the load distribution on the trailer. We express the part of the involved trailer weight as a percentage of the entire weight or the “Effective Mass Ratio” (represented by the Greek letter gamma γ).
Eccentricity

- Definitions:
  - Central collision – a crash where an extension of the PDOF passes through the vehicle’s center of mass
  - Eccentric Collision - – a crash where the extension of the PDOF misses the vehicle’s center of mass
Increasing Eccentricity
Increasing Eccentricity

But as eccentricity increases, the difference between the DeltaV as sensed by the ACM and the DeltaV at the area of crash damage (damage centroid) also increases.

The amount of eccentricity is defined by the measure “h” or the lever-arm.
Effective Mass Ratio

- The DeltaV as sensed at the EDR can never be greater than the DeltaV at the damage center.
- The DeltaV at COM for the other vehicle is determined by Equation 12: \( \Delta V_2 = -\frac{w_1 \Delta V_1}{w_2} \)
- Then the DeltaV at COM for the other vehicle is adjusted by the Effective Mass Ratio.
- Determine or estimate your lever arm or “h” in feet.
- Use the table below to **estimate** the Effective Mass Ratio.

<table>
<thead>
<tr>
<th>When “h” is</th>
<th>0 Feet</th>
<th>1 Foot</th>
<th>2 Feet</th>
<th>3 Feet</th>
<th>4 Feet</th>
<th>5 Feet</th>
<th>6 Feet</th>
<th>7 Feet</th>
<th>8 Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0m</td>
<td>0.3m</td>
<td>0.61m</td>
<td>0.91m</td>
<td>1.22m</td>
<td>1.52m</td>
<td>1.83m</td>
<td>2.13m</td>
<td>2.44m</td>
</tr>
<tr>
<td>Effective Mass Ratio</td>
<td>1 (Central Collision)</td>
<td>.95</td>
<td>.83</td>
<td>.70</td>
<td>.57</td>
<td>.45</td>
<td>.37</td>
<td>.30</td>
<td>.25</td>
</tr>
</tbody>
</table>
Eccentricity Example Problem

Q: The EDR in the 3250 lb (1475 kg) red car records a Lateral DeltaV of 6.8 mph (10.9 kph). What is the approach speed for the 4600 lb (2088 kg) striking vehicle (Crown Vic)?
Eccentricity Example Problem

- Step 1: Determine h for both vehicles. In this case the CAD diagram indicates that h was 8 feet (2.44m) for the red car and 1 foot (0.30m) for the Crown Vic.

- Step 2: Use the table to estimate the EMR for both vehicles.

<table>
<thead>
<tr>
<th>When “h” is</th>
<th>0 Feet</th>
<th>1 Foot</th>
<th>2 Feet</th>
<th>3 Feet</th>
<th>4 Feet</th>
<th>5 Feet</th>
<th>6 Feet</th>
<th>7 Feet</th>
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<tbody>
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<td></td>
</tr>
<tr>
<td>Effective Mass Ratio</td>
<td>1 (Central Collision)</td>
<td>.95</td>
<td>.83</td>
<td>.70</td>
<td>.57</td>
<td>.45</td>
<td>.37</td>
<td>.30</td>
<td>.25</td>
</tr>
</tbody>
</table>

- In this case EMR\(_{\text{Red Car}}\) = .25, and EMR\(_{\text{Crown Vic}}\) = .95
Eccentricity Example Problem

• Step 3: Given the EDR DeltaV in the red car use Equation 12 to calculate the Crown Vic DeltaV for a **central collision**

\[ \Delta V_1 = - \Delta V_2 \frac{W_2}{W_1} \]

**Equation 12**

Substituting

\[ \Delta V_1 = -6.8 \frac{3250}{4600} \]

\[ = (10.9 kph) \frac{1475}{2088} \]

\[ = 7.7 kph \]

• Step 4: Next we need to calculate the Closing Speed based on the DeltaVs
Eccentricity Example Problem

- Step 5(maybe): We might be tempted to use the Closing Speed equation for Central Collisions (Equation 9A w/o restitution)

\[ \text{Closing Speed} = |\Delta V_1| + |\Delta V_2| \]

Closing Speed = 6.8\,mph + 4.8\,mph

Closing Speed = 11.6\,mph

Closing Speed = 10.9 + 7.7\,kph

Closing Speed = 18.7\,kph
Eccentricity Example Problem

- Step 6 - And, since the red car was stopped, we would be tempted to invoke equation 8c and say that the closing speed of 11.6 mph was the actual approach speed of the Crown Vic. This would be true if this was a central collision.

\[ 8(C) \text{ Speed } V_1 = \text{ Closing Speed } + \text{ Speed } V_2 \]

\[ \text{ Speed } V_1 = 11.6 + 0 = 11.6 \text{ mph} \]

\[ = 18.7kph + 0 = 18.7 \text{ kph} \]

- Unfortunately the analysis is not that simple. We need to correct for the eccentric nature of this crash
Eccentricity Example Problem

- Proper Step 5: Since this is an eccentric collision we use the Closing Speed equation with EMR corrections (Equation 9c). We just calculated the DeltaVs with Equation 12. Recall earlier we found the EMRs with the table for both vehicles:

\[
\text{ClosingSpeed} = \left[\frac{1}{1+e} \right] \left[ \frac{|\Delta V_1|}{\gamma_1} + \frac{|\Delta V_2|}{\gamma_2} \right]
\]

\[
\begin{align*}
\text{Closing Speed} &= \frac{4.8}{.95} + \frac{6.8}{.25} \\
&= 7.7 + 27.2 \\
&= 8.1 + 43.8 \text{ kph} \\
&= 51.9 \text{ kph}
\end{align*}
\]
Eccentricity Example Problem

- Step 6: And the previous observation holds, since the red car was stopped, the closing speed of 32.25 mph (51.9 kph) was the actual approach speed of the Crown Vic.

- Compare the results with and without the EMR adjustment:

  - Closing Speed Without EMR 11.6 mph (18.7 kph)
  - Closing Speed With EMR 32.25 mph (51.9 kph)
Source of Effective Mass Ratio

• Previously we saw EMR was related to “h” the lever arm
• EMR is also related to the properties of the vehicle.
  – Weight
  – Size
  – Construction (FWD, RWD, Mid-Engine, etc)
• Weight, Size and Construction type determine the Yaw Moment of Inertia.

\[ \gamma = \frac{k^2}{k^2 + h^2} \quad \text{Where} \quad k^2 = \frac{\text{Yaw Moment of Inertia (g)}}{\text{Vehicle Weight}} = \frac{I_y g}{W} \]

\[ I_y = 1.03(\text{weight in lbs}) - 1206 \quad \text{* (sorry no metric equivalent)} \]

• Previously we simplified the process by using a table

Effective Mass Ratios for Different Vehicles

Effective Mass Ratio for Various Vehicle Types

- Honda Fit
- Toyota Camry
- Crown Vic
- Honda CRV
- Chev Tahoe
- F150 Xtra Cab Pickup

Table Based off Values For a Toyota Camry
Steps to Assessing Eccentricity 1

• Understand the physical evidence in your collision
• Understand your PDOF.
• Stand in front of the damaged area of the car and visualize the PDOF with your arm. Visualize the PDOF extension. Does its extension pass through the vehicle’s CM?
  – PDOF extensions that pass through CM are central hits
  – PDOF extensions that miss CM are eccentric hits
    • The greater the miss the more eccentric the collision
    • The size of the miss is the lever arm “h” in feet
• Sketch your vehicles at maximum engagement and sketch the equal and opposite PDOFs
Steps to Assessing Eccentricity 2

• CAD Diagrams are better than a sketch. Scale the damaged vehicles and fit them back together
• Take overhead photos

• Compare the EDR longitudinal and lateral crash pulses for similar durations. Similar durations indicate a central collision
• Post crash rotation indicates an eccentric collision
• Use the Effective Mass Ratio table to find the DeltaV adjustments so that you can calculate closing speed.
Eccentricity - Conclusions

- DeltaV is a powerful means to calculate closing speed, and approach speed in *central collisions*.
- The Effective Mass Ratio for slightly eccentric collisions (within 1 foot) is small $EMC_{(1 \text{ Foot})} = .95$
- If $h$ is within 1 foot of a central collision, the error is within 5% - less than the 10% DeltaV range – Treating it as a central collision is reasonable
- Using a DeltaV equation for a central collision in an eccentric collision with $h$ greater than 1 foot will underestimate closing speed –
- In the case of a closing speed calculation it will estimate a minimum.
- The greater the eccentricity, the greater underestimate

$$\text{Closing Speed} = |\Delta V_1| + |\Delta V_2|$$
Other Offset Crash Complications

- Some ACM’s are mounted *forward* of the CG
- In frontal and near *frontal* crashes the PDOF line is relatively in line with the vehicle X axis, any additional adjustment from ACM location to CG location is relatively small.
- In perpendicular crashes where the PDOF is *behind* the CG, the effect is more noticeable. A recent SAE paper on accuracy of Y Delta V in *side* crashes noted EDR Delta V underestimated the true Delta V.
- The paper acknowledged **EDR location** as a possible cause but did not explore the relationship quantitatively. A parallel axis theorem calculation would be needed. At this time, no EDR classes suggest adjusting further for this.
- For further information on Effective Mass Ratio take the IPTM Level 2 EDR class or seek help from someone who has had the Energy Methods class.
Cautions Using Delta V information

7a. GROUND FORCES – Subtract them out

- In traditional recon we explicitly IGNORE ground forces during collisions
- In low speed or low Delta V collisions ground forces may be significant.
- Example 1: Driver sees ped, slams on brakes, hits Ped resulting in an actual 1 mph DeltaV from ped hit. Slowing due to braking during the crash adds

\[-0.7g(32.2\text{fps/s})(0.150\text{seconds})\]
\[\frac{1.466(\text{fps/mph})}{1.466(\text{fps/mph})} = -2.3\text{mph}\]

\[-0.7g(9.8\text{mps/s})(0.15\text{0sec})(3.6\text{kph/mps}) = -3.7\text{kph}\]

- So the EDR DeltaV includes slowing due to braking (ground) forces during the collision
- Delta V of Ped Hit = -3.3mph EDR - 2.3 ground forces = -1.0 mph PED ΔV
  = -5.3kph EDR - 3.7ground forces = -1.6 kph PED ΔV
SLOWING DUE TO CRASH

1FTRF12W49KB Longitudinal Crash Pulse (First Record)

SLOWING DUE TO BRAKING

7 MPH DUE TO CRASH

END OF CRASH

MPH

Millisconds
Cautions Using Delta V information

7a. GROUND FORCES – Subtract them out

- As a result the 3.3 mph (5.3 kph) Delta V in the EDR includes the 2.3 mph (3.7 kph) that is not attributable to collision forces.
- In this case we should subtract the DeltaV induced by ground force before calculating the other vehicle’s (the pedestrian) DeltaV via inversely proportional DeltaV.

\[
\Delta V_{\text{Bullet}} = -\Delta V_{\text{Target}} \frac{W_{\text{Target}}}{W_{\text{Bullet}}}
\]

Equation 12

Warning: Working with small DeltaVs in vehicles much heavier than the object struck creates highly sensitive calculations for the lighter object. In many circumstances it may not be appropriate for use with a pedestrian collision. Ped collisions are further complicated by the ped mass not always fully coupling to the vehicle mass, except in full forward projections.
Cautions using Delta V information

7b. GROUND FORCES – Add them back in

- Example 2: A stationary car equipped with an EDR is struck squarely in the side by a motorcycle. The tires are unable to roll and the car is pushed fully sideways. The EDR in the car documents a 10 mph lateral DeltaV.

- In this case, not only does the motorcycle accelerate the car by 10 mph via crash forces, but it must also push the car sideways on a 0.8 f surface during the crash.

- First let's estimate the ground forces

\[
-0.8g \left(\frac{32.2\text{fps/s}}{s}\right)\left(0.150\text{seconds}\right) = -2.6\text{mph}
\]

\[
\frac{-2.6\text{mph}}{1.466\text{mph/fps}} = -2.6\text{mph}
\]

- Delta V of MC Hit = +10.0mph EDR - 2.6 ground forces = 12.6 mph Crash ΔV
Cautions Using Delta V information

7b. GROUND FORCES – Add them back in

- Next we recognize that the Motorcycle is the source of both the EDR DeltaV and the forces that were applied to the ground as the car moved sideways during the crash.
- As a result we add the estimated 2.6 mph (4.2 kph) ground force loss to the EDR documented 10 mph (16.1 kph) Delta V to have an estimate of the forces brought to the collision from the motorcycle 12.6 mph (20.3 kph)
- If we wanted to calculate the motorcycles DeltaV via Equation 12 we would use the 12.6 mph (20.3 kph) DeltaV as the DeltaV Target.

\[ \Delta V_{\text{Bullet}} = -\Delta V_{\text{Target}} \frac{W_{\text{Target}}}{W_{\text{Bullet}}} \]  

Equation 12

- *Warning: Working with small DeltaVs and or great weight or momentum disparity creates highly sensitive calculations for the lighter vehicle*
Cautions Using Delta V Information

8. Unusual DeltaV Curve Shape

- Recall that DeltaV is calculated as the area under the Crash Pulse Curve as it is sensed by the Airbag Control Modules accelerometers.
- Sometimes two events in rapid succession can be captured in a single recording, resulting in a “double hump”.
- We should always check to be sure that our Cumulative DeltaV has its familiar shape.
- Non standard curve shape can also be the result of severe rotation, or very small DeltaVs and/or DeltaV resolution.
Normal DeltaV Curve Shape

- This is a Cumulative DeltaV curve from a Toyota
- The curve has the expected shape
- Even though the crash magnitude is small (7.5 mph) this is good data

- Starts near Zero
- Levels off at a peak value
- The duration (90 ms) is a little short but it is reasonable
8a. Unusual Delta V Curve Shape – Multiple Impacts

This is from the second car in a chain reaction inline collision – after being hit from behind it hits the car in front, then car behind catches up again.
8b. Unusual Delta V Curve Shape – Severe Rotation At Impact

This is a Cumulative Lateral DeltaV curve from a Honda that is hit on the left front which then pivots CCW, trips, and rolls.

PDOF is changing during crash – do not take arc tangent of peak lateral over peak longitudinal at different time to get PDOF.
Cautions using DeltaV information

8c. Unusual curve shape due to small magnitudes

How can we explain this unusual Curve

This is a Cumulative Lateral DeltaV curve from a GM Product

This curve does not have the expected shape.

We note that this graph is ‘auto-scaled.’

The magnitude is very small (0.7 mph)
DeltaV – Unusual DeltaV Curve Shape
8d. Small Magnitudes (often secondary axis)

The best conclusion would be that there was no (significant) lateral DeltaV component to this crash.

This lateral DeltaV would just be “noise.”
DeltaV – Unusual Curve Shape

8e. Truncated recording

Or we might ask: why this module stopped documenting DeltaV when the crash was clearly not over yet?

Cumulative DeltaV not “flat” yet
In this case we find the explanation in the Data Limitations.

For Deployment Events, the SDM will record 100 milliseconds of data after Deployment criteria is met and up to 50 milliseconds before Deployment criteria is met.

- 4 pre-D spaces not used
- All 10 post-D spaces used
- We don't know what happened after 100 ms post D

100ms
DeltaV – Unusual Curve Shape

8f. Small Short Pulse (Snowplow trip, stump pull)

Pre Crash Braking

-0.21 mph of DV from Pre Crash Braking. 25% of total DV

Substantial -11.5 Peak g

“Crash” Ends. Cumulative DV becomes flat for a -0.81 mph Total DV

Crash Pulse is 5 ms long, too short to be conventional crash

-50 ms 0 ms +50 ms
Delta V – unusual curve shapes
8g. Load shifting or not changing mass of entire vehicle

• In small Delta V’s such as motorcycle to car impacts, the initial impact may move the body but due to compliance in the body mounts the chassis does not respond immediately. The Delta V may correct to a lower magnitude when all the mass finally couples.

• In other cases a loose load may initially not change velocity – when it comes to a constraint the full mass Delta V is realized – but this can be delayed until after the end of the Delta V graph and not be recognized.
Cautions using Delta V information

9. Unintended consequences of Part 563

CFR 49 Part 563 regulates how Delta V data is recorded. It requires recording a time series every 10ms from 0 to 250ms after algorithm wake up (typically displayed on a graph), and that it keeps track of cumulative maximum Delta V up to 300ms from wakeup.

If the algorithm wakes up on a curb but the car goes on to hit a tree at past 300ms while the algorithm is still running, it may show only the curb hit on the graph. NHTSA does not require the manufacturer to include Delta V after 300ms in the single value max Delta V. It does require the manufacturer to report the time of the maximum Delta V. If the time = 300ms be suspicious some portion of the event was still going on. If the time is >300ms, the manufacturer keeps recording until the algorithm stops.
Algorithm woke up early, missed later event
Noted in newer Fords, Mazda & Kia/Hyundai

### System Status at Event (Event Record 1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Belt Status, Driver</td>
<td>Belted</td>
</tr>
<tr>
<td>Safety Belt Status, Right Front Passenger</td>
<td>Unbelted</td>
</tr>
<tr>
<td>Occupant Size Classification, Front Passenger</td>
<td>Adult</td>
</tr>
<tr>
<td>Frontal Air Bag Warning Lamp (On, Off)</td>
<td>Off</td>
</tr>
<tr>
<td>Ignition Cycle, Crash</td>
<td>1892</td>
</tr>
<tr>
<td>Multi-Event, Number of Events (1, 2)</td>
<td>No. 1</td>
</tr>
<tr>
<td>Complete File Recorded (Yes/No)</td>
<td>Yes</td>
</tr>
<tr>
<td>Ignition Cycle, Download</td>
<td>1893</td>
</tr>
<tr>
<td>Maximum Delta-V, Longitudinal (MPH [km/h])</td>
<td>1.2 [2]</td>
</tr>
<tr>
<td>Time, Maximum Delta-V, Longitudinal (msec)</td>
<td>297.5</td>
</tr>
<tr>
<td>Maximum Delta-V, Lateral (MPH [km/h])</td>
<td>-1.2 [-2]</td>
</tr>
<tr>
<td>Time, Maximum Delta-V, Lateral (msec)</td>
<td>297.5</td>
</tr>
</tbody>
</table>

### Deployment Command Data (Event Record 1)

<table>
<thead>
<tr>
<th>Command</th>
<th>Time (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretensioner Deployment, Time to Fire, Driver</td>
<td>250</td>
</tr>
<tr>
<td>Pretensioner Deployment, Time to Fire, Right Front Passenger</td>
<td>250</td>
</tr>
<tr>
<td>Frontal Air Bag Deployment, Time to Deploy/First Stage, Driver</td>
<td>250</td>
</tr>
<tr>
<td>Frontal Air Bag Deployment, Time to Deploy/First Stage, Right Front Passenger</td>
<td>250</td>
</tr>
</tbody>
</table>

Max Value
Mazda
Signs of “early” wakeup

- Ford devotes TWO bytes to deploy time, if deploy time is higher than 300ms the deploy DV is not captured in the printed max.
- Kia/Hyundai max deploy time is 253ms (anything 250-255 should be suspicious)
Cautions using Delta V information

9. Unintended consequences of Part 563

CFR 49 Part 563 defines end of event as when cumulative delta-V within a 20 ms time period becomes 0.5 mph (0.8 km/h) or less, or algorithm shutoff.

This usually does a good job of determining end of event, but under rare circumstances, it fails. Recent case: 115 mph impact, 49 mph (78.8 kph) ΔV, but as car skids to rest ΔV is still being measured over 0.5 mph/20ms – recorder reports ΔV as 56 mph (90.1 kph) at 300ms but crash was over at 100ms.

Always review the Delta V graph to make sure the end of event choice for the single value was rationale.
Longitudinal Crash Pulse (First Record)

**Graph:**
- **X-axis:** Milliseconds
- **Y-axis:** MPH
- **End of Crash:** Marked at 0.5 MPH

**Table:**

<table>
<thead>
<tr>
<th>Time (msec)</th>
<th>Delta-V, longitudinal (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-0.10</td>
</tr>
<tr>
<td>10</td>
<td>-0.73</td>
</tr>
<tr>
<td>20</td>
<td>-1.53</td>
</tr>
<tr>
<td>30</td>
<td>-2.56</td>
</tr>
<tr>
<td>40</td>
<td>-3.66</td>
</tr>
<tr>
<td>50</td>
<td>-4.42</td>
</tr>
<tr>
<td>60</td>
<td>-4.90</td>
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<tr>
<td>70</td>
<td>-5.35</td>
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<td>80</td>
<td>-5.75</td>
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<td>90</td>
<td>-6.41</td>
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<td>100</td>
<td>-7.08</td>
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<tr>
<td>110</td>
<td>-7.80</td>
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<td>120</td>
<td>-8.53</td>
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<td>140</td>
<td>-9.45</td>
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<td>150</td>
<td>-9.83</td>
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<td>160</td>
<td>-9.95</td>
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<tr>
<td>170</td>
<td>-10.13</td>
</tr>
<tr>
<td>180</td>
<td>-10.27</td>
</tr>
<tr>
<td>190</td>
<td>-10.38</td>
</tr>
<tr>
<td>200</td>
<td>-10.43</td>
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<tr>
<td>210</td>
<td>-10.39</td>
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<td>220</td>
<td>-10.43</td>
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<tr>
<td>230</td>
<td>-10.43</td>
</tr>
<tr>
<td>240</td>
<td>-10.47</td>
</tr>
<tr>
<td>250</td>
<td>-10.44</td>
</tr>
</tbody>
</table>
Cautions in Using Delta V Information
9. Unintended Consequences of Part 563

- Mfr MUST record if ΔV_x > 5mph (8 km/h) within 150 ms. Manufacturer MAY record at lower threshold (Nissan, Hyundai), most don’t.
- For vehicles with ΔV_γ, must record if either ΔV_x or ΔV_y exceeds 5mph (8 km/h) within 150 ms. (Toyota records side impacts at a lower threshold)

Small and low DeltaV impacts <5mph may not recorded (unless mfr kept a lower threshold).

Most pedestrian strikes will not be recorded.
Cautions in using Delta V information

9. Unintended Consequences of Part 563

- *Time zero* means whichever of the following occurs first:
- (1) For systems with “wake-up” air bag control systems, the time at which the occupant restraint control algorithm is activated; or
- (2) For continuously running algorithms,
  - (i) The first point in the interval where a longitudinal cumulative delta-V of over 0.8 km/h (0.5 mph) is reached within a 20 ms time period; or
  - (ii) For vehicles that record “delta-V, lateral,” the first point in the interval where a lateral cumulative delta-V of over 0.8 km/h (0.5 mph) is reached within a 5 ms time period; or
- (3) Deployment of a non-reversible deployable restraint.

This part of 563 defines the beginning of the crash pulse.
10. Small Delta V’s

- Small Delta V accuracy is affected by the RESOLUTION of the place it is stored.
- Some manufacturers TRUNACATE the Delta V to the NEXT LOWER WHOLE KPH, and then have CDR *round* it to the nearest mph. It is more precise to start with the kph value. Others may report to a precision of 0.01 mph – we don’t need to worry about those!
- If an EDR reports a small Delta V of 3kph, we need to be aware it may have measured 3.00 to 3.99. Both would be reported as 3. If the small Delta V is important, you can “range it” from the value shown to the next higher value.
Small Delta V Accuracy with 1mph or 1 kph Resolution of Delta V

- Actual is a range 0 to +0.99 more than reported
# DeltaV Accuracy +/-10%

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Full Scale</th>
<th>Resolution</th>
<th>Accuracy</th>
<th>How Measured</th>
<th>When Updated</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔV</td>
<td>± 55.9 mph</td>
<td>0.4 mph</td>
<td>~ ± 10%</td>
<td>integrated acceleration</td>
<td>recorded every 10 msec, calculated every 1.25 msec.</td>
</tr>
<tr>
<td>Vehicle Speed</td>
<td>158.4 mph</td>
<td>0.6 mph</td>
<td>± 4 %</td>
<td>Magnetic pickup</td>
<td>vehicle speed changes by ≥ 0.1 mph</td>
</tr>
<tr>
<td>Engine Speed</td>
<td>16383 RPM</td>
<td>1/4 RPM</td>
<td>± 1 RPM</td>
<td>Magnetic pickup</td>
<td>RPM changes by ≥ 32 RPM.</td>
</tr>
<tr>
<td>Throttle Position</td>
<td>100% Wide open throttle</td>
<td>0.4 %</td>
<td>± 5%</td>
<td>Rotary potentiometer</td>
<td>Throttle position changes by ≥ 5%.</td>
</tr>
</tbody>
</table>

**Recording Automotive Crash Event Data (1999)**

Augustus "Chip" Chidester, National Highway Traffic Safety Administration  
John Hinch, National Highway Traffic Safety Administration  
Thomas C. Mercer, General Motors Corporation  
Keith S. Schultz, General Motors Corporation
Delta V Accuracy

1999 Chidester Paper (w/GM authors) stated

“Accuracy is +/-10%” - generally accepted.

NOTE: +/-10% does NOT include clipping or other special circumstances. It applies primarily to accelerometer accuracy and reporting resolution during moderate severity crashes.

Some papers report high DV tests as being more than -10%, those are suspected of being cases of clipping.

Also, for very small accelerations and DV’s, accelerometer RESOLUTION is 0.5G typical, so 0.9G may report as 0.5G resulting in more than 10% error.

Analog accelerometers present in 1999 have largely been replaced by digital accelerometers, and may have higher ranges. Manufacturers advise the +/-10% margin still applies to the newer digital accelerometers.
Reconciling EDR Delta V Information to momentum & crush analysis

• As always, you must consider **all the available information** and **how reliable** each piece of that information is. Evaluate EDR Delta V considering the 9 special circumstances listed previously. Use appropriate ranges on all data.

• Make a **LINE GRAPH** of your speed at impact ranges from EDR Delta V and Momentum (or Crush) and identify where they overlap:

<table>
<thead>
<tr>
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<tbody>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>47 mph</td>
<td>55 mph</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>50 mph</td>
<td>59 mph</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>50 mph</td>
<td>55 mph</td>
</tr>
</tbody>
</table>

• The overlap is where the preponderance of the evidence points to and should be your consensus speed at impact.

• In moderate crashes, Delta V may provide a more precise range of speeds at impact than precrash speed data does.
Disagreement between EDR $\Delta V$ and Scene Evidence

| | | \----------------Momentum/Crush----------------|
| | | 67 mph | 77 mph |
| | | \----------EDR Delta V \------| | \--------------EDR Speed Data (if available) \------|
| 50 mph | 59 mph | 65 | 79 | \------Preponderence of Evidence \------|
| Under reported due to clipping | 67 mph | 77 mph |

- If the ranges do not overlap or overlap only narrowly with EDR less than scene evidence, *something is wrong*, question everything. Evaluate if any of the 9 special circumstances have affected your $\Delta V$. Also double check how good your scene evidence is (drag factor, departure angle) and make sure they are appropriately ranged. If you assess that CLIPPING is likely (particularly in severe head-on crashes) then *DISCOUNT SPEEDS DERIVED FROM EDR $\Delta V$ AND USE THE AVAILABLE SCENE EVIDENCE OR EDR SPEED DATA*. In moderate crashes, $\Delta V$ may provide a more precise range of speeds at impact than precrash speed data does.
Recommended Practice:
Delta V reconciliation worksheet 3-151
Acceleration Data Only?
(Chrysler 08-09, Toyota 13 EDR Lateral)

• You can use Microsoft Excel to calculate the Delta V from the Accel Data.

• You can save the file as a “CSV” then copy data in to templates in your reference materials.

• Judgement is required for **WHEN** to **START** accumulating Delta V and **WHEN** to **STOP** on Chrysler data.

• **Leave out** precrash braking and postcrash skidding.
Take Delta V only for *Crash* Pulse

Possible Precrash Braking

Possible Postcrash Skid

USE CSV FEATURE TO GRAPH AND CALCULATE DELTA V

-100

0=deploy

+150
Airbag Deployment Decisions

As reconstructionists, it is NOT OUR JOB to determine if airbags should have deployed or not. Airbag deployment algorithms are very complex & proprietary to the supplier. Algorithms must PREDICT if the airbag will be needed based on the first few milliseconds of a crash.

- How bad is the crash **RIGHT NOW** (G’s)
- How much Cumulative Delta V has there been **SO FAR**
- Is the crash getting **more severe** with time or is it getting **less severe** with time (Jerk)

In addition to the airbag control module sensor, modern systems have one or two *auxiliary* electronic crash sensors on the front rad support that also go into the decision. Some mfr’s also modify the airbag decision based on seat belt use. Auxiliary Sensor data is not typically available in the Bosch CDR report.
Suggestion: Don’t offer opinions on whether airbags should have deployed!

Many underrides that push the hood back but don’t engage frame rails, or narrow objects that penetrate between the frame rails, look horrific at first glance but do NOT meet the airbag deployment threshold – they start very gently.

Many crashes that look benign at first glance, such as full frontal contract crashes engaging both frame rails where bumper fascias spring back to the original shape and disguise the damage hidden behind it, DO meet the airbag deployment threshold.

Automakers respectfully request you not stir up undeserved product liability lawsuits when you really are not qualified to render an opinion – you don’t know the algorithm and you don’t know the inputs from the aux sensors.
End of Generic Delta V Analysis