Consortium Website

All data from crash testing and this presentation will be available at

http://tucrrc.utulsa.edu

Credentials
User: TUCRRCmember
Password: TUCRRCpassword
Running into Trailers

- Common theme for crash testing
  - IPTM 2004
  - IPTM 2012
  - IATAI 2013
  - Tennessee 2014
  - TAARS 2014

- Common occurrence on highways and interstates.
Order of Presentation

- Crash Test Videos
- Crash Testing Setup and Instrumentation
- Rotational Mechanics Analysis
- Restitution Analysis
- Aggregated Crash Test Analysis
IPTM Special Problems
IPTM Special Project
Open Quicktime to watch videos
TAARS 2014 Summary

Crash 1
- 2005 Chrysler Sebring
- Weight: 3395 lbs
- Impact Speed
  - Vbox 3i: 46.11 mph
  - Video Vbox: 45.66 mph
  - eGPS-200: 45.86 mph

Crash 2
- 2004 Mercury Sable
- Weight: 3043 lbs
- Impact Speed
  - Vbox 3i: 45.98 mph
- Rear Dual Displacement: 13.5 ft
- Angle of trailer rotation: ~24.5 deg
DATA ACQUISITION SYSTEMS AND SETUP
Racelogic VBox 3i

- 100Hz GPS system
- Serial (CAN) communication
- Compact flash logging
- Brake trigger
- Inertial Measurement Unit
  - Tri-axial accelerometer
  - Tri-axial gyroscope
Racelogic Video VBox

- 10Hz/20Hz GPS system
- 4 Cameras
- Microphone
- Compact flash logging
eDAQ Data Acquisition

- Rugged system designed for use in harsh environments
- Enables simultaneous and synchronous recording of multiple channels with different types of instruments
- Convenient data recording modes
- Proprietary interface

Infield Software

- 4 Layers
- DIO
  - Digital I/O
- HLS
  - High level analog
- ECOM
  - Vehicle network communications
Instruments

- **eGPS-200Plus**
  - Combines data from 2 GPS antennas and IMU to provide several kinematic measurements at 200Hz

- **Measurements**
  - Acceleration (All 3 axis)
  - Angular velocity (All 3 Axis)
  - Speed
  - Heading, altitude, longitude
  - Slip angle
Instruments

- **Accelerometer**
  - Tri-axial measurements
  - $\pm 250$ gs
  - 5,000 Hz bandwidth

- **Gyroscope**
  - Tri-axial measurements
  - $\pm 600$ deg/s rates
  - 400 Hz bandwidth
eDAQ Data Recording Modes

- **Time history**
  - Records continuously

- **Burst history**
  - **Buffer data**
  - Records data in a predefined interval
  - Simplifies data processing
Interface (Web)

- Limited access
- Manage networked cameras
- Quick test startup
VC4000DAQ

- 10Hz GPS
- Brake pedal sensor
- Tri-axial accelerometer
  - Used to determine drag coefficient
Attaching Accelerometer
SAE Sign Convention
Crash Test 1 Data

INLINE IMPACT

CHRYSLER SEBRING INTO TRAILER
System Momentum

- System Momentum In + External Impulse = System Momentum Out
- Planar components: X, Y, and θ.
- A system is defined as something you can define a boundary with.
  - Consistent boundary (Eularian system)
  - Consistent Objects (Lagrangian system)
- Forces act on boundaries.
Inline system

- System defined as the two vehicles where the interaction boundary is the road surface.
  - External impulses occur at the boundary.
  - Don’t need to include collision forces
- Can also define the boundaries around each vehicle.
  - Need to include both collision forces and road forces.
Foundations

- **Work and Energy:**
  - Kinetic Energy In = Damage Energy + Kinetic Energy Out

- **Impulse and Momentum**
  - Momentum In + External Impulse = Momentum Out
  - External Impulse can be from collision forces and friction

- **Kinematics**
  - Speed in + Delta V = Speed Out
  - Restitution = \( \frac{(V_{1,in} - V_{2,in})}{(V_{2,out} - V_{1,out})} \)
Inline Crash

DATA FROM INSTRUMENTS
Vbox 3i Data

Graph:
- Y-axis: m/s
- X-axis: Seconds
- Line graph showing acceleration over time.

Data Table:
- Run Time: 0 Minutes 42.240 Seconds
- Cursor (Seconds): 16.658
- Speed (mph): 46.11
- LatAcc (g): 1.930
- LongAcc (g): 1.478
- Heading (Degrees): 174.645
- Height (feet): 551.476
- Relative Height (feet): -3.998
- Vertical Speed (mph): -0.294
- Satellites (Number of): 8
- Glonass Satellites (Number of): 0
- GPS Satellites (Number of): 8
- Yaw Rate (/s): 
- Latacc from Yaw Sensor 2 (g):
- Latitude (Minutes): 1981.930
- Longitude (Minutes): 5836.632
- Brake Trigger (ON/OFF): 0.000
- DGPS (ON/OFF): 0.000

TAARS 2014 http://tucrrc.utulsa.edu
eDAQ Synchronized Data

- **eDAQlite_Data_Crash1_TX2014.sif - eGPS@speed_3d.RN_1**
  - speed_3d (km/h)
  - Time (secs): 90, 92, 94, 96, 98, 100, 102
  - accel_x_05 (g)

- **eDAQlite_Data_Crash1_TX2014.sif - VBox_3i@VBVelocity.RN_1**
  - VBVelocity (knots)
  - Time (secs): 90, 92, 94, 96, 98, 100, 102

- **eDAQlite_Data_Crash1_TX2014.sif - IMU@accel_x_05.RN_1**
  - accel_x_05 (g)
  - Time (secs): 90, 92, 94, 96, 98, 100, 102
Impact Speeds

- **45.86 mph**
- **46.22 mph**
Chrysler Delta V in X

Delta V = -49.6 mph

Delta T = 139 msec
Separation after impact
Relative Accelerations

- Near Impact
- Middle of Trailer
- Tractor Platform
Same Scale (X Direction)
Z- Axis Accelerations

eDAQ_Data_crash1_TX2014.sie - IMU_data@Accel_Z_06.RN_1
eDAQ_Data_crash1_TX2014.sie - IMU_data@Accel_Z_43.RN_1
eDAQ_Data_crash1_TX2014.sie - GPS@accel_z.RN_1

Time (secs)
402.5 403.0 403.5 404.0
Accel_Z_06 (g)
-40
-20
0
20
40

http://tucrrc.utulsa.edu
Delta-V in X from all Accels

Rear X Accel.
Middle X Accel.
Tractor Accel (e-GPS)

Time (secs)
402.0 402.5 403.0 403.5 404.0 404.5 405.0 405.5

Delta V (mph)

x:402.3874  y:0.010843  n:441  x:402.5234  y:4.31572  dx:0.136  dy:

x:402.3874  y:0.00528648  n:616  x:402.5234  y:4.30905  dx:0.136  dy:

x:402.385  y:0.008784  n:72  x:402.525  y:4.09444  dx:0.14  dy:
Zoomed in on Delta-V
(4.3 mph in 115 msec)

Rear X Accel.

Middle X Accel.

Tractor Accel (e-GPS)

Delta V (mph)

Time (secs)

402.30 402.35 402.40 402.45 402.50 402.55 402.60 402.65
Observations

- Rigid body assumption:
  - Common delta-V values for the whole rig
  - Common times
  - Confidence of measurements

- Acceleration data shows shock attenuation
  - 150 g’s near impact
  - 4 g’s at cab

- eGPS accelerometer has too much damping (not great for shock events)
Restitution

- Impact speed of car: 46 mph
- Delta V of Car: 49.6 mph
- Post impact Speed of car: -3.6 mph (~0)
- Impact Speed of Trailer: 0 mph
- Post Impact Speed (Delta V) of Trailer: 4.3 mph

\[ e = \frac{V_{1,\text{out}} - V_{2,\text{out}}}{V_{2,\text{in}} - V_{1,\text{in}}} = \frac{-3.6 - 4.3}{0 - 46} = 0.172 \]
Reconstruction Strategy

- Assume known speed of tractor-trailer

- If not an underride:
  - Calculate Delta V from Crush
  - Assume restitution of 0.1-0.2 for impact speed

- If underride:
  - Look for EDR data...
  - Crush analysis doesn’t account for some energies.
  - 50% low estimate on impact speed for Chrysler in this case.
  - Closing speeds are almost always low.
TAARS 2014 Crash #2:

SABLE INTO TRAILER DUALS AT 90 DEGREES
Crash 2 Video
Chapter 9: Rotational Mechanics
## Tractor Trailer Axle Data

### Weights

<table>
<thead>
<tr>
<th>Axle Weights (lb)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Left</strong></td>
<td>4820</td>
<td>2900</td>
<td>2320</td>
</tr>
<tr>
<td><strong>Front</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Right</strong></td>
<td>4480</td>
<td>3320</td>
<td>2180</td>
</tr>
<tr>
<td><strong>Steer</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Drive 1</strong></td>
<td>-</td>
<td>3320</td>
<td>-</td>
</tr>
<tr>
<td><strong>Drive 2</strong></td>
<td>-</td>
<td>2180</td>
<td>-</td>
</tr>
<tr>
<td><strong>Trailer 1</strong></td>
<td>-</td>
<td>1750</td>
<td>-</td>
</tr>
<tr>
<td><strong>Trailer 2</strong></td>
<td>-</td>
<td>2300</td>
<td>-</td>
</tr>
</tbody>
</table>

Total: 28,410 lb

### Portable Scales

[Image of portable scales with weights]
Weights from Wrecker

- Box Van Landing gear: 4640 lb
- Box Van Rear Axles: 7800 lb
- Volvo Steer Axle: 8200 lb
- Volvo Drive Axles: 7240 lb
- Total Combined Weight: 27,880 lb
  - Compared to 28,410 lb from other scales (2% difference)
- Mercury Sable: 2968 + 75 = 3043 lb
- Chrysler Sebring: 3320 + 75 = 3395 lb
Mercury Impact Speed
\(~46\) mph (Crash 2)
Delta V: ~38 mph
Rear Dual Displacement
Angle of Rotation

24.6 Deg
What About Trailer Rotation?

- Assume the Trailer is a Rigid Body rotating around the king pin
  - Tractor did move a little
  - Trailer had rolling motion
  - Angular quantities are the same everywhere

- Acceleration of Rigid Body
  \[ \hat{a}_P = \hat{a}_O + \hat{\alpha} \times \hat{r}_{P/O} + \hat{\omega} \times (\hat{\omega} \times \hat{r}_{P/O}) \]

- Y direction accel. depends on lever arm
Graphic of Rotation

\[ \omega \times (\omega \times \hat{r}_{P/O}) \]

\[ \alpha \times \hat{r}_{P/O} \]
Y Axis Accelerations

Note: Middle Accelerometer (blue) was mounted with z axis up and y axis out driver’s side (opposite SAE).
Zoomed on Y Accelerations

- Rear Trailer Accelerometer (Y)
- Middle Accelerometer (Y)
- Tractor Accelerometer (Y)

Time (secs)

783.70 783.75 783.80 783.85 783.90 783.95 784.00

Acceleration (g)

-100
-67
-33
0
33
67
100

TAARS 2014

http://tucrrc.utulsa.edu
Delta V in Y for Tractor

Tractor Accelerometer in Y

Time (secs)
782 784 786 788 790 792 794

Delta V (mph)
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0

x:793.056  y:No Data  n:No Data
Delta V in Y near Impact

Calculated from Y Accel near impact

Time (secs)
783.5, 784.0, 784.5, 785.0, 785.5, 786.0, 786.5, 787.0, 787.5

Delta V (mph)
-20, -15, -10, -5, 0, 5
Delta V Comparison

Calculator_00239.sif - Tractor Y Accel
Calculator_00247.sif - Impact Y Accel
Calculator_00248.sif - Middle Y Accel

Time (secs)
784.0 784.5 785.0 785.5 786.0
Delta V (mph)
-20
-15
-10
-5
0
5

TAARS 2014
http://tucrrc.utulsa.edu
Trailer Crash Pulse

Calculations:
- Calculator_00239.sif - Tractor Y Accel
  - x:783.7  y:-0.000373315  n:32
  - x:783.79  y:0.206446  dx:0.09  dy:
- Calculator_00247.sif - Impact Y Accel
  - x:783.699  y:-0.106395  n:648
  - x:783.7876  y:-17.6722  dx:0.0886  dy:
- Calculator_00248.sif - Middle Y Accel
  - x:783.699  y:-0.020098  n:555
  - x:783.7876  y:-8.25932  dx:0.0886  dy:

Graph:
- Time (secs): 783.70, 783.75, 783.80, 783.85, 783.90
- Delta V (mph): -20, -15, -10, -5, 0, 5

Analysis:
- 88 ms
- -8.23 mph
- -17.55 mph

TAARS 2014  http://tucrrc.utulsa.edu
Yaw and Roll Rate of Trailer

![Graphs showing Yaw and Roll Rate](image-url)
Trailer to Truck Yaw Rate Comparison

eDAQ_Data_crash2_TX2014.sie - IMU_data@Yaw_48.RN_1

eDAQ_Data_crash2_TX2014.sie - GPS@yaw_rate.RN_1

Time(secs)
784.0 784.5 785.0 785.5 786.0

Yaw_48(deg/sec)
-150
-100
-50
0
50
100
150
200

http://tucrcc.utulsa.edu

TAARS 2014
Yaw and Roll Rate
Restitution
Yaw and Roll Angle

![Graph showing Yaw and Roll Angle over time](image-url)
Estimate Initial average Angular Velocity

Slope = 37.84 deg/s
Mercury Speed

Graph

http://tucrrc.utulsa.edu
Restitution Estimation

- Mercury Impact Speed: 46 mph
- Mercury Post Impact Speed: ~8 mph
- Post Impact Point Velocity: ~16 mph

\[ e = \frac{V_{1,\text{out}} - V_{2,\text{out}}}{V_{2,\text{in}} - V_{1,\text{in}}} \approx \frac{8 - 16}{0 - 46} = 0.17 \]
Inertial Properties of Trailer

A FACTBOOK OF THE MECHANICAL PROPERTIES OF THE COMPONENTS FOR SINGLE-UNIT AND ARTICULATED HEAVY TRUCKS

Paul S. Fancher
Robert D. Ervin
Christopher B. Winkler
Thomas D. Gillespie

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109

December 1986

Sample of Semitrailers Yaw and Pitch Moments of Inertia (Empty Units)

in-Lbs-sec²

48' Semitrailer, Tandem Axle, WB=40' (1,328,867)

45' Semitrailer, Tandem Axle, WB=37' (1,093,878)

42' Semitrailer, Tandem Axle, WB=36' (945,019)

http://deepblue.lib.umich.edu/handle/2027.42/118
Sample of Semitrailer Weights (Empty Units) lbs

- 48' Semitrailer, Tandem Axle, WB=40' (13,800) (measured value for a 1985 product)
- 45' Semitrailer, Tandem Axle, WB=37' (13,043)
- 42' Semitrailer, Tandem Axle, WB=36' (12,286)

Actual Crash Weight: 12,440 lb
Center of Mass Location

Sample of Semitrailer Fore-aft C.G. Location (inches behind the kingpin)

300.00

48’ Semitrailer Empty, Tandem Axle (301.56’’)

275.00

45’ Semitrailer Empty, Tandem Axle (282.30’’)

250.00

42’ Semitrailer Empty, Tandem Axle (268.74’’)

48’ Semitrailer Loaded, Tandem Axle (263.31’’)

225.00

45’ Semitrailer Loaded, Tandem Axle (254.08’’)

42’ Semitrailer Loaded, Tandem Axle (228.21’’)

http://tucrrc.utulsa.edu
Tractor & Semitrailer Dimensions (inches): FROM CG (For HVE Simulation)
Comparison to other Crashes

TENNESSEE CONFERENCE
2014
Mapping data
EDR DATA FROM UNDERRIDES
GMC Envoy Crash Video
No Air Bag Deployment
Photo of Non-deployment
Photo of Non-deployment
## System Status At Non-Deployment

<table>
<thead>
<tr>
<th>Feature</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIR Warning Lamp Status</td>
<td>OFF</td>
</tr>
<tr>
<td>Driver’s Belt Switch Circuit Status</td>
<td>BUCKLED</td>
</tr>
<tr>
<td>Ignition Cycles At Non-Deployment</td>
<td>29018</td>
</tr>
<tr>
<td>Ignition Cycles At Investigation</td>
<td>29019</td>
</tr>
<tr>
<td>Maximum SDM Recorded Velocity Change (MPH)</td>
<td>-43.09</td>
</tr>
<tr>
<td>Algorithm Enable to Maximum SDM Recorded Velocity Change (msec)</td>
<td>357.5</td>
</tr>
<tr>
<td>Crash Record Locked</td>
<td>No</td>
</tr>
<tr>
<td>Event Recording Complete</td>
<td>Yes</td>
</tr>
<tr>
<td>Multiple Events Associated With This Record</td>
<td>No</td>
</tr>
<tr>
<td>One Or More Associated Events Not Recorded</td>
<td>No</td>
</tr>
</tbody>
</table>

## Seconds Before AE

<table>
<thead>
<tr>
<th>Seconds Before AE</th>
<th>Vehicle Speed (MPH)</th>
<th>Engine Speed (RPM)</th>
<th>Percent Throttle</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5</td>
<td>27</td>
<td>1152</td>
<td>0</td>
</tr>
<tr>
<td>-4</td>
<td>31</td>
<td>1216</td>
<td>0</td>
</tr>
<tr>
<td>-3</td>
<td>35</td>
<td>1152</td>
<td>0</td>
</tr>
<tr>
<td>-2</td>
<td>39</td>
<td>1216</td>
<td>0</td>
</tr>
<tr>
<td>-1</td>
<td>43</td>
<td>1216</td>
<td>0</td>
</tr>
</tbody>
</table>
GMC Envoy ABS and $\Delta v$ Crash Data

![Bosch Logo]

<table>
<thead>
<tr>
<th>Seconds Before AE</th>
<th>Brake Switch Circuit State</th>
</tr>
</thead>
<tbody>
<tr>
<td>-8</td>
<td>OFF</td>
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<tr>
<td>-7</td>
<td>OFF</td>
</tr>
<tr>
<td>-6</td>
<td>OFF</td>
</tr>
<tr>
<td>-5</td>
<td>OFF</td>
</tr>
<tr>
<td>-4</td>
<td>OFF</td>
</tr>
<tr>
<td>-3</td>
<td>OFF</td>
</tr>
<tr>
<td>-2</td>
<td>OFF</td>
</tr>
<tr>
<td>-1</td>
<td>OFF</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (milliseconds)</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recorded Velocity Change (MPH)</td>
<td>-2.48</td>
<td>-4.03</td>
<td>-5.89</td>
<td>-8.99</td>
<td>-10.54</td>
<td>-12.40</td>
<td>-15.50</td>
<td>-17.98</td>
<td>-19.84</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (milliseconds)</th>
<th>100</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
</tr>
</thead>
</table>

TAARS 2014

http://tucrrc.utulsa.edu
GMC Envoy EDR $\Delta v$

GMC Envoy $\Delta v$ vs. Time

$\Delta v$ (mph)

Time (ms)
Accuracy of EDR Data

- To test accuracy of EDR Data a reference accelerometer was mounted behind the passenger seat of the crash vehicle.
GMC Envoy Crash Acceleration Impulse

Crash Impulse Acceleration

- Accelerometer

Time (ms)

Acceleration (g)
GMC Envoy $\Delta v$ comparison

GMC Envoy $\Delta v$ vs. Time

- Accelerometer
- CDR

Maximum recorded velocity change

$\Delta v$ (mph)

Time (ms)
Chevy S10 $\Delta v$ comparison

Chevy S10 $\Delta v$ vs. Time

- Accelerometer
- CDR

$\Delta v$ (mph) vs. Time (ms)

TAARS 2014

http://tucrrc.utulsa.edu
Accuracy of EDR Data

- Based on the data provided by the reference accelerometer, the EDR $\Delta v$ is accurate
  - Similar shape in $\Delta v$ vs. time graphs validate EDR data

- Trend line can be used to extrapolate data past the 150ms memory threshold
When do air bags deploy?

- At the onset of an event, the ACM detects acceleration sufficient to wakeup the crash sensing / decision making algorithm.

- Based on an evaluation of the sensed acceleration, potentially along information from auxiliary sensors, the ACM makes a decision to Deploy or Not Deploy the supplemental restraints.
Predictive Decision Making

- The ACM decision is anticipatory based on pre-programmed criteria
  - “Jerk” and other criteria are evaluated as long as the crash sensing algorithm is awake
- It does not / can not wait for some minimum delta-v threshold to be met
- Deployment decision has to be made early to allow time for airbag inflation
It is generally held the ideal decision window is ~15-50ms to allow for airbag inflation before occupant contact.
Deployment Timing Example
Deployment Timing Example
Less than ideal timeline
When air bags may not deploy

1. Collisions where there are extreme deformations, where only one portion of the front of the car is deformed as when colliding with a telephone pole.

2. Collisions where the impact is gradual as when driving under the load space of a truck.

3. Collisions where the collision barrier is greatly deformed or relocated as in cases of side impact with a passenger car.

4. Collisions where the impact direction is dispersed or the vehicle greatly moves while colliding as in cases of oblique impacts.
THP 2014 - Crash #1
### System Status At Non-Deployment

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### Seconds Before AE, Vehicle Speed (MPH), Engine Speed (RPM), Percent Throttle

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<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>-1</td>
<td>43</td>
<td>1216</td>
<td>0</td>
</tr>
</tbody>
</table>
THP 2014 - Crash #1
Deployment Timing Example
THP 2014 - Crash #2
THP 2014 - Crash #2
THP 2014 - Crash #2

System Status At Deployment

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<tbody>
<tr>
<td>SIR Warning Lamp Status</td>
<td>OFF</td>
</tr>
<tr>
<td>Driver’s Belt Switch Circuit Status</td>
<td>UNBUCKLED</td>
</tr>
<tr>
<td>Passenger SIR Suppression Switch Circuit Status (if equipped)</td>
<td>Air Bag Not Suppressed</td>
</tr>
<tr>
<td>Ignition Cycles At Deployment</td>
<td>27681</td>
</tr>
<tr>
<td>Time Between this Event and the Previous Event (sec)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Seconds Before AE</th>
<th>Vehicle Speed (MPH)</th>
<th>Engine Speed (RPM)</th>
<th>Percent Throttle</th>
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<tbody>
<tr>
<td>-5</td>
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<td>1024</td>
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<tr>
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<td>35</td>
<td>1024</td>
<td>0</td>
</tr>
<tr>
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<tr>
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<tr>
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<td>1024</td>
<td>0</td>
</tr>
</tbody>
</table>

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THP 2014 - Crash #2

S10 Change in Velocity vs. Time

Change in Velocity (mph)

Time (ms)

Accelometer
CDR
Chevy S10 Crash Video
Displacement Angle

\[ \theta = \tan^{-1} \left( \frac{7.8}{37.6} \right) = 0.204 \text{ rad} = 11.72^\circ \]
Chevy S10 Pre-Crash Data

System Status At Deployment

<table>
<thead>
<tr>
<th>SIR Warning Lamp Status</th>
<th>OFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver's Belt Switch Circuit Status</td>
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<td>-5</td>
<td>30</td>
<td>1024</td>
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<tr>
<td>-1</td>
<td>48</td>
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<td>0</td>
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</table>
## Chevy S10 ABS and $\Delta v$ Crash Data

<table>
<thead>
<tr>
<th>Seconds Before AE</th>
<th>Brake Switch Circuit State</th>
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<tr>
<td>-8</td>
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<tr>
<td>-7</td>
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</tr>
<tr>
<td>-6</td>
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<tr>
<td>-1</td>
<td>OFF</td>
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</table>

<table>
<thead>
<tr>
<th>Time (milliseconds)</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
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<th>80</th>
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<tbody>
<tr>
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<td>-0.14</td>
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<td>-11.33</td>
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</table>

<table>
<thead>
<tr>
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<th>90</th>
<th>100</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
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<tbody>
<tr>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Chevy S10 EDR $\Delta v$

Chevy S10 $\Delta v$ vs. Time

Time (ms)

$\Delta v$ (mph)

$\Delta v$ (mph) vs. Time

CDR

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Combined EDR $\Delta v$

Chevy S10 and GMC Envoy $\Delta v$ vs. Time

$\Delta v$ (mph) vs. Time (ms) for Chevy S10 and GMC Envoy.
Jerk Defined

- In physics:
  - also known as jolt, surge, or lurch

- Jerk = the rate of change of acceleration
  - the derivative of acceleration with respect to time
  - the second derivative of velocity
  - the third derivative of position.
Jerk – Related to Airbag Deployment Decision Making
Jeremy Daily on

DETROIT DIESEL ECM DATA AND NETWORK TRAFFIC
Graph Data

Last Stop Time: 05/28/14 12:21:19 (EST)

Last Stop Odometer: 346,469.4 mi

Vehicle Speed (mph)

Engine RPM

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### Table Data

<table>
<thead>
<tr>
<th>Time</th>
<th>Vehicle Speed (mph)</th>
<th>Engine Speed (rpm)</th>
<th>Brake</th>
<th>Clutch</th>
<th>Engine Load (%)</th>
<th>Throttle (%)</th>
<th>Cruise</th>
<th>Diag. Code</th>
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<tr>
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<tr>
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<tr>
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<td>13.50</td>
<td>0.00</td>
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<td>0.00</td>
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<td>No</td>
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<td>0.00</td>
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<tr>
<td>+0:02</td>
<td>0.0</td>
<td>590</td>
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<td>No</td>
<td>13.00</td>
<td>0.00</td>
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<tr>
<td>+0:03</td>
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<td>No</td>
<td>8.00</td>
<td>0.00</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Detroit Diesel Diagnostic Link (DDDL)

- Compare ECM Time Clock

![Real-time Clock](image)

ECU Time: 2014/05/28 12:43:32

Warning: Ensure that the PC time zone is correct before setting the real-time clock.

Time Zone: Central Daylight Time

Set the real-time clock to match the PC time...

PC Time: 2014/05/28 13:34:37

...or set the real-time clock to a specific time.

Custom Time: 2014/05/28 13:33:44

Note that the real-time clock values are displayed in the computer's local time zone.
Speed Record Comparison

Speed Record for Freightliner Tractor

- Wheel-Based Vehicle Speed (mph)
- Road Speed (mph)
- Front Axle Speed (mph)
- DDEC Reports Speed (mph)
Remarks

- Impulse and Momentum data is insufficient to calculate speeds
- DeltaV from hvEDR data is not resolved well
- Vehicle Network speed has more samples, thus making it a candidate for data, if available.
- hvEDR follows the J1587 Road Speed Data.
ROTATIONAL MECHANICS ANALYSIS FOR RIGHT ANGLE IMPACT
S-10 Crash Analysis

- Location of Center of Mass of Trailer
- Mass Moment of Inertia of Trailer
- Lateral Displacement of Trailer (Displacement Angle)
- Angular Velocity of Trailer
- Calculating S-10 delta-V
- Calculating pre-impact velocity of S-10
- Accuracy of Calculations vs. Equipment Data
Determining the location of Center of Mass (C.M.) using Static Analysis

<table>
<thead>
<tr>
<th>Location</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>LG</td>
<td>3800</td>
<td>4400</td>
</tr>
<tr>
<td>RA1</td>
<td>2600</td>
<td>1800</td>
</tr>
<tr>
<td>RA2</td>
<td>2200</td>
<td>1900</td>
</tr>
</tbody>
</table>

Total Trailer Weight \( (W_{\text{total}}) = 16,700 \text{ lb.} \)
Determining the location of Center of Mass (C.M.) using Static Analysis
Determining the location of Center of Mass (C.M.) using Static Analysis

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Determining the location of Center of Mass (C.M.) using Static Analysis

\[ \sum M_O = 0 \rightarrow W_{RA1}(d_1) + W_{RA2}(d_2) - W_{TOTAL}(X) + W_{LG}(d_3) = 0 \]
Determining the location of Center of Mass (C.M.) using Static Analysis

\[ X = \frac{W_{RA1}(d_1) + W_{RA2}(d_2) + W_{LG}(d_3)}{W_{TOTAL}} \]

Location of C.M. from the rear of the trailer.

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Determining the location of Center of Mass (C.M.) using Static Analysis

\[
X = 24.5 \text{ ft}
\]

Location of C.M. from the rear of the trailer.
Displacement Angle

7.75 ft
• Def: Measure of a body’s resistance to rotational acceleration about a specified axis of rotation.
• Depends on geometry and location of axis of rotation.
• If axis of rotation is NOT through center of mass, then Parallel Axis Theorem must be used.
Rotational Mechanics-
Mass Moment of Inertia (Yaw)

\[ I_z = \frac{1}{12} m(b^2 + L^2) \]

m…mass
b…width of trailer
L…length of trailer

Units: lb-ft-s^2, slug-ft^2

\[ I_{z,CM} = \frac{1}{12} \left( \frac{16700}{32.2} \right)(8.5^2 + 50.3^2) \]

\[ I_{z,CM} = 112,471.73 \, lb \cdot ft \cdot s^2 \]
Rotational Mechanics - Parallel Axis Theorem

\[ I_{Z, KP} = I_{Z, KP} + md^2 \]

\[ I_{Z, KP} = 112,471.73 + \left( \frac{16700}{32.2} \right)(22.6^2) \]

\[ I_{Z, KP} = 378,308.8 \text{ lb} \cdot \text{ft} \cdot \text{s}^2 \]
Rotational Mechanics - Angular Velocity

Assumptions:
- 50/50 Left/Right Weight Distribution
- Fully rigid king-pin
- Estimate drag-factor (f)

\[
\omega = \sqrt{\frac{2wfh\theta}{I_{z, kp}}} \quad \text{(eq. 9.67)}
\]

- \( f \)…estimated drag factor (0.6-0.7)
- \( w \)...weight
- \( h \)...KP to LOI
- \( \theta \)...displacement angle
- \( I \)...mass moment of inertia about the King-pin
Rotational Mechanics - Angular Velocity

Plug in numbers...

\[ \omega = \frac{\sqrt{2 \times 0.7 \times 16700 \times 35.3 \times 0.204}}{378308.8} \]

\[ \omega = 0.534857 \text{ rad/sec} \]
Delta-V of S-10

\[ \Delta v = \frac{I_{z,kp} \omega}{mh} \]  
(eq. 9.60)

\[ \Delta v = \frac{(378,308.8)(0.535)}{(3430/32.2)(35.3)} \]

\[ \Delta v = 53.9 \frac{ft}{s} = 36.7 \text{ mph} \]
Pre-Impact Velocity of S-10 ($v_1$)

\[ v_1 = \frac{v_4 + \Delta v}{1 + e} \]  
(eq. 9.72)

$e$ ...Coefficient of restitution (typically 0 - 0.15). Ratio of speeds after and before impact. 1 – elastic & 0 – perfectly inelastic.

$\nu_4 = h\omega$ ...linear post-impact velocity of trailer

$\nu_1 = \frac{(35.3)(0.535) + 53.9}{1 + 0}$

$\nu_1 = 72.7$ ft/sec = 49.62 mph
### Calculations vs. Instrument Data

<table>
<thead>
<tr>
<th>Calculated</th>
<th>Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f$</td>
<td>$v_1$</td>
</tr>
<tr>
<td>0.6</td>
<td>45.94</td>
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<tr>
<td>0.65</td>
<td>47.81</td>
</tr>
<tr>
<td>0.7</td>
<td>49.62</td>
</tr>
</tbody>
</table>

This demonstrates that the principles based on Newtonian physics hold true with a small margin of error. Often times, this is all we have to rely on when no other facts/data are available.
Consortium Website

All data from crash testing and this presentation will be available at

http://tucrrc.utulsa.edu

Credentials
User: TUCRRCmember
Password: TUCRRCpassword
Safe Travels.

THANK YOU