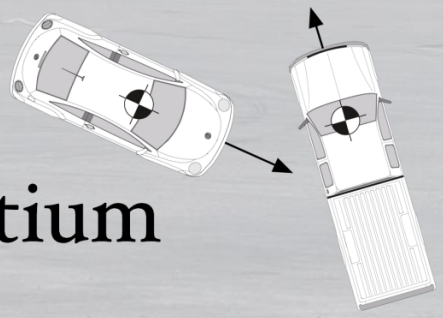
PSP Recon Seminar 2014

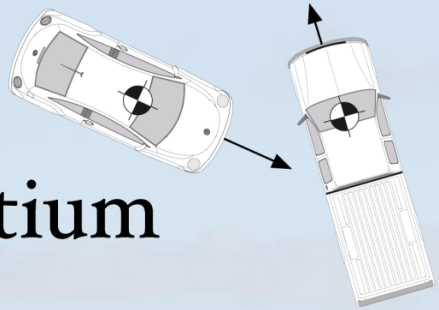
Crash Data Review

THE UNIVERSITY of TULSA

Crash Reconstruction Research Consortium



Crash Reconstruction Research Consortium



- Brad Muir - Crash Data Specialists
- Jon Northrup - Crash Data Specialists
- Andy Rich – Rich Consulting
- Vlad Bortchevsky – Crash LLC
- Greg Russell – Accident Analysis & Reconstruction
- Dan Vomhof III – 4N6XPRT Systems

CRASH DATA SPECIALISTS
WWW.CDR-TRAINERS.COM

Rich Consulting LLC
office (234) 201-7676
fax (234) 678-0246

crash™
Collision Reconstruction And Scientific Hypothesis LLC

ACCIDENT ANALYSIS & RECONSTRUCTION, INC

4N6XPRT Systems®

Thanks too……

- PA State Police
- PCARS
- Walmart for a great facility and lunch!
- Chris Kelley
- Justin Pisano
- Mike Grassi
- Kevin Forcier
- Anyone we have left off !!

Consortium Website

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

http://tucrrc.utulsa.edu

Credentials

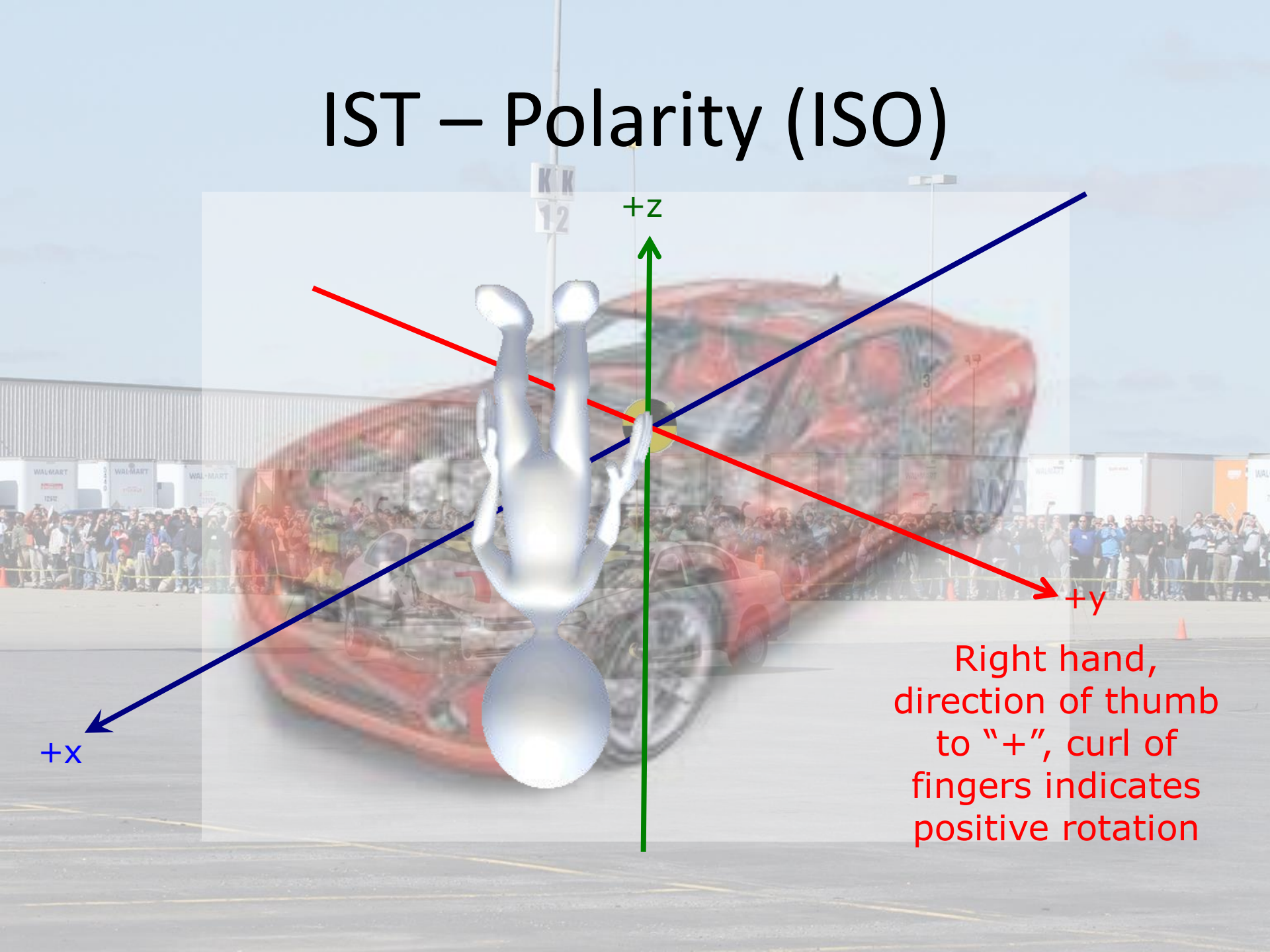
User: TUCRRCmember

Password: TUCRRCpassword

Instrumentation

- IST – Instrumented Sensor Technology
  - EDR3C / 3D Tri-axial accelerometers sampling at 3072hz
  - EDR3D Motion Master Tri-axial accelerometer at 3072hz
    - Includes 3 – axis angular rate

IST – Polarity (ISO)



Instrumentation

- Video Vbox Lite
  - GPS speeds for all vehicles
  - 2 x Hi-Res Video Cameras
  - 10HZ Sample rate
- Vbox Sport
  - Tow Vehicle Speed

UAV Video / Photo

- DJI Phantom Vision 2+
- ~$1600 with accessories
- 700m range
  - ~2200 feet
- Camera - 3-axis stabilized
- 14 mega-pixel
- 1080p Video
- 25 minute flight time

The Plan!!!

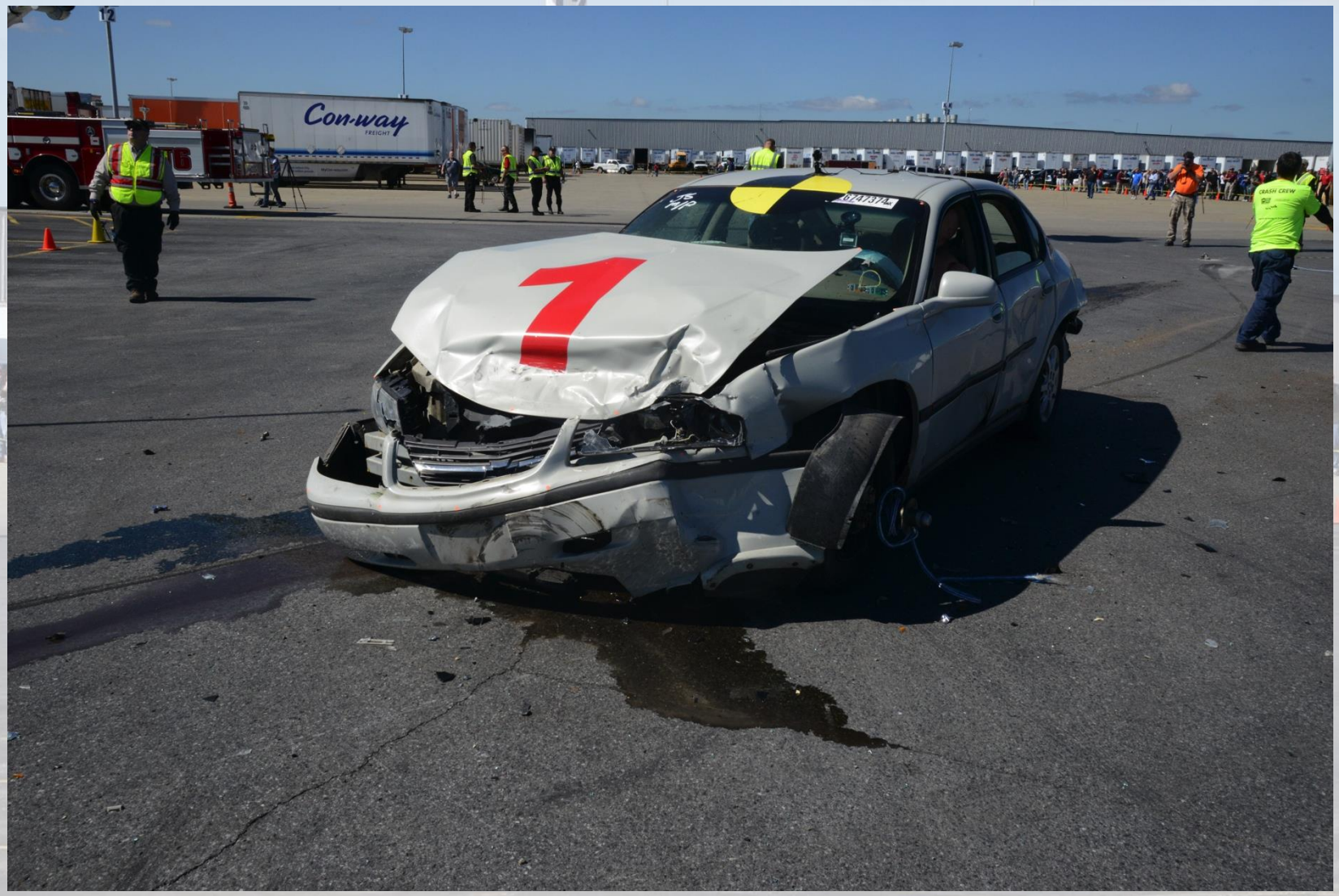
- Construct a 2 vehicle collision with a high closing speed
- CMV to Car collisions to look at effective mass ratio in eccentric impacts
- Examine Relevant CDR data based on collision setup and dynamics
- Explore “360” momentum concepts

Crash Test #1

2003 Chevrolet Impala vs. 2005 Chevrolet Malibu

2003 Chevrolet Impala

3200 lbs



Overhead View - UAV

2005 Chevrolet Malibu

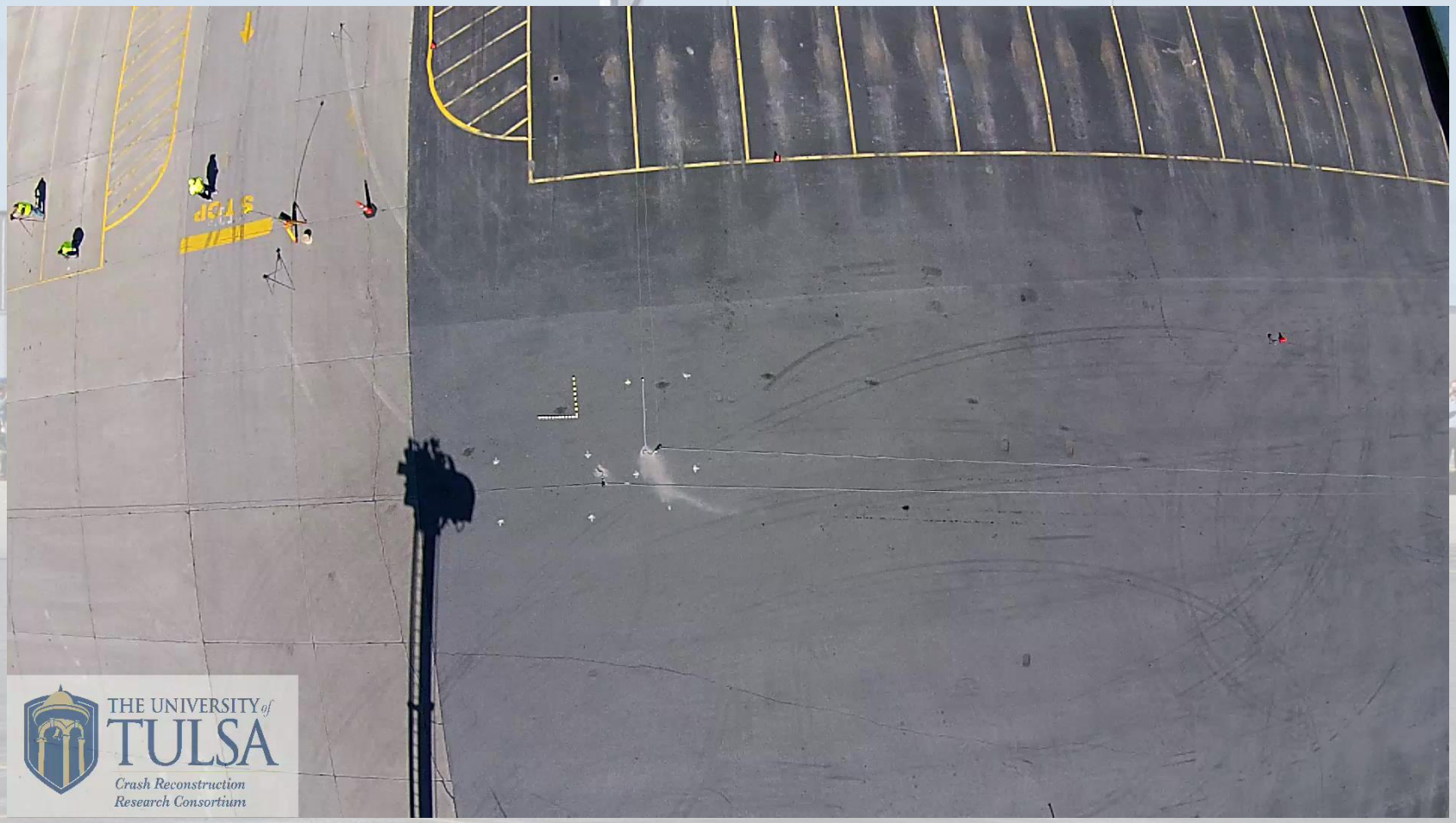
3080 lbs

Overhead View - UAV

Crash Test #1 - Video

Crash Test #1 - Video

Crash Test #1 - Video



Crash Test #1 - Video

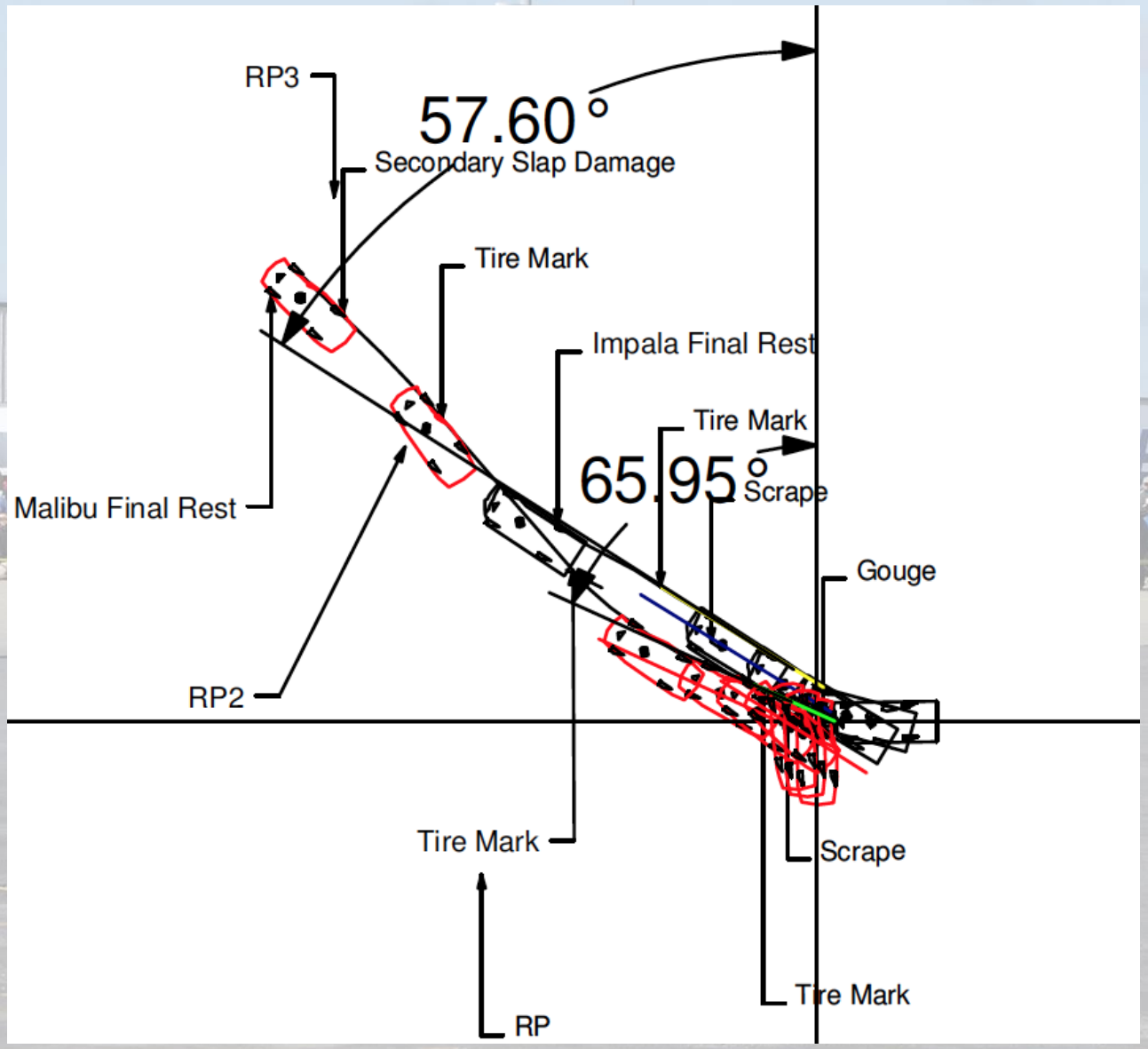
Crash Test #1 - Video

Crash Test #1 - Video

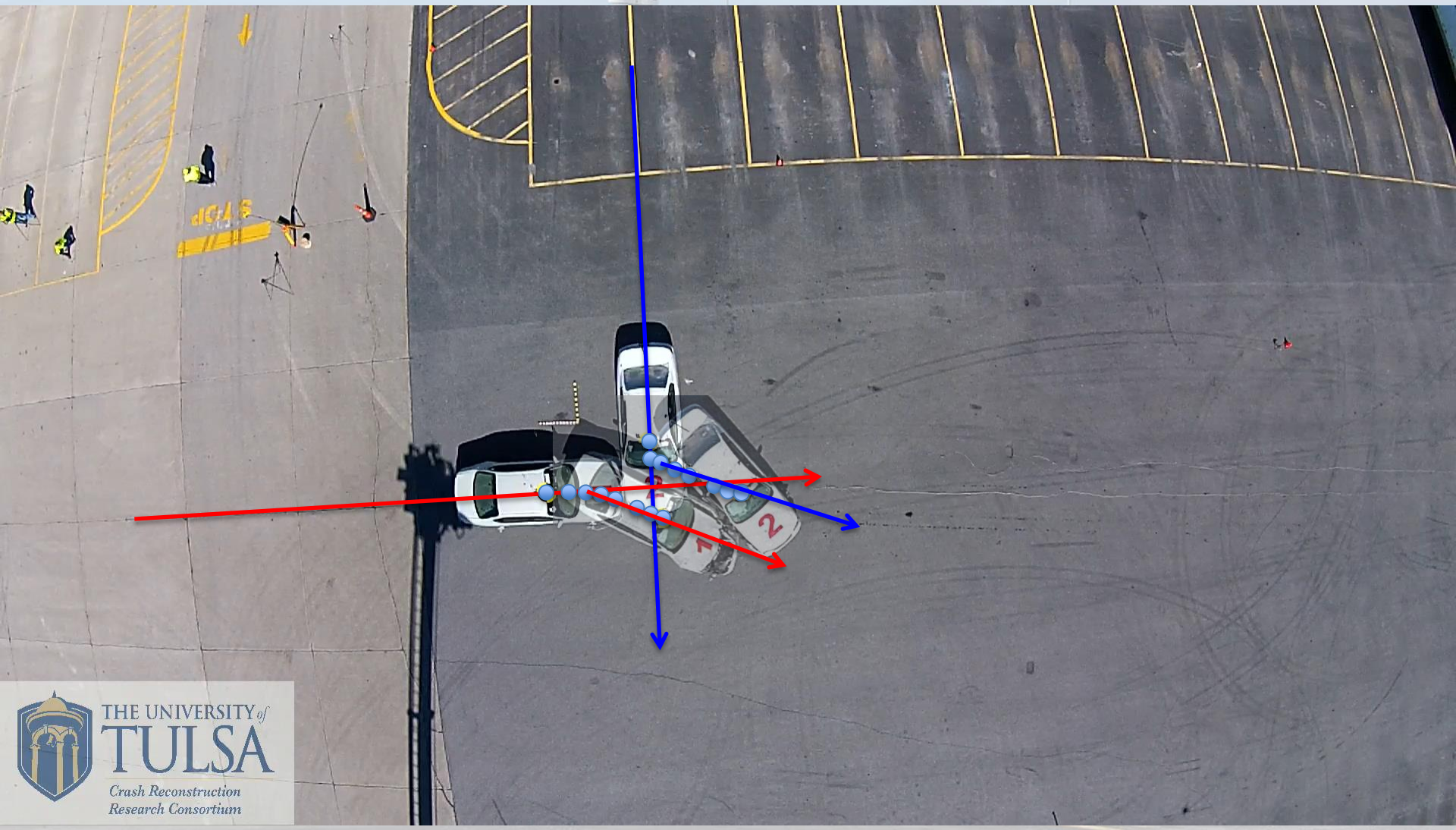
The Scene……

The Scene….

The Scene


RP3
57.60°
Secondary Slap Damage
Tire Mark
Impala Final Rest
Tire Mark
65.95°
Scrape
Malibu Final Rest
Gouge
RP2
Tire Mark
Scrape
Tire Mark
RP

Momentum Solution



Momentum Solution

Units of Measure	Angle Direction	Send Data to Microsoft Word	Angle Sensitivity Range
Imperial	Counterclockwise		

	Vehicle #1		Vehicle #2
	3,080	Vehicle Weight (pounds)	3,200
	0.0°	Approach Headings	90.0°
	63.0°	Departure Headings	67.0°

Enter any 2 speeds from either vehicle's impact or post impact speeds

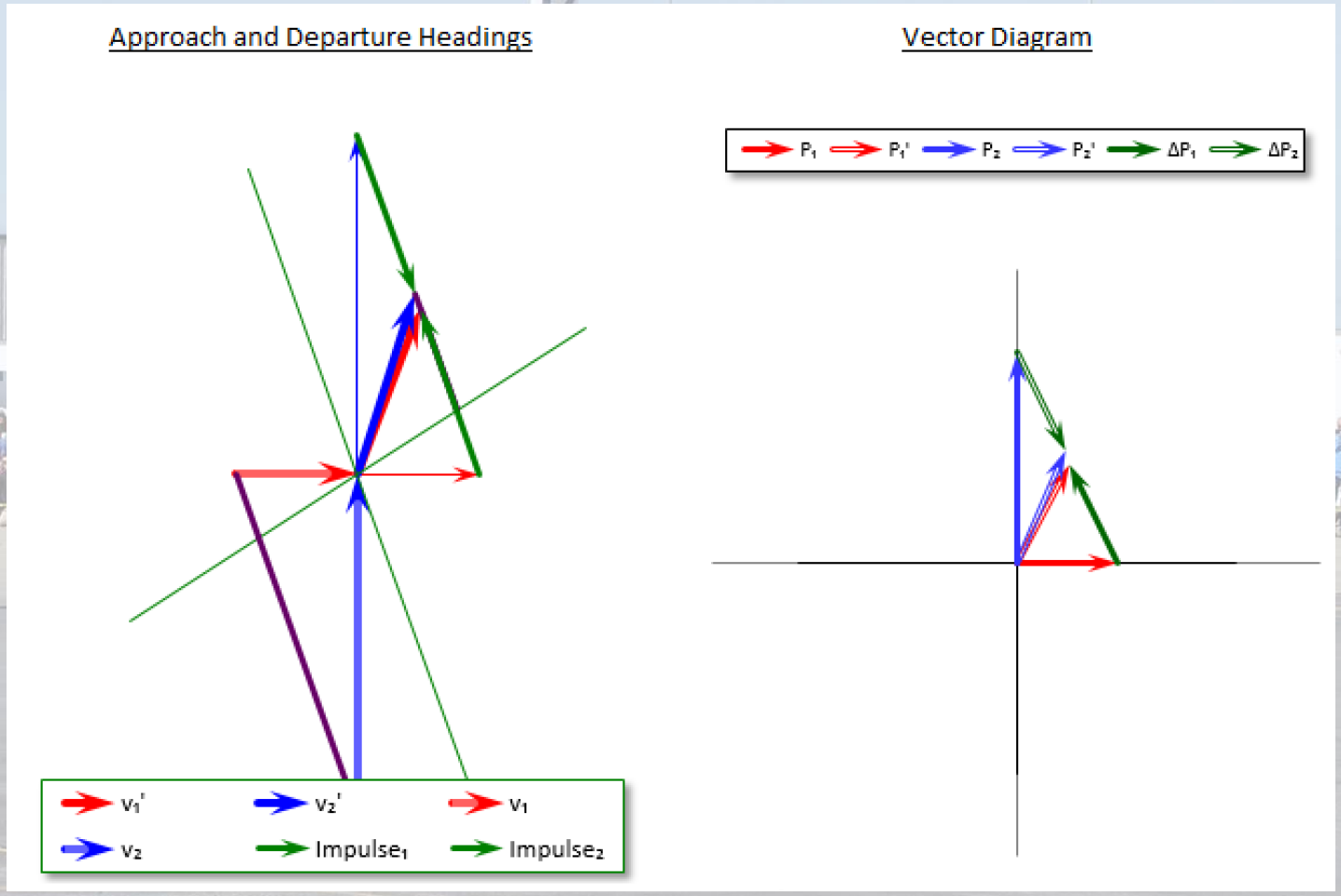
Vehicle #1 Post Impact Speed	24.6 mph
Vehicle #2 Post Impact Speed	26.0 mph

	Impact Velocity: v	Post Impact Velocity: v'	Change in Velocity: Δv	$pdof$
Vehicle #1	21.7 mph : 31.8 fps	24.6 mph : 36.1 fps	24.3 mph : 35.7 fps	64.3°
Vehicle #2	45.0 mph : 66.0 fps	26.0 mph : 38.1 fps	23.4 mph : 34.3 fps	-25.7°

	Impact Energy: E_k	Separation Energy: E_k'	Combined ΔE_k	Pdof Check
Vehicle #1	48,490 ft lb	62,316 ft lb	130,499 ft lb	Valid
Vehicle #2	216,649 ft lb	72,323 ft lb		

Closing Velocity	50.0 mph : 73.3 fps	Separation Velocity	2.3 mph : 3.3 fps	Restitution: 0.045

Momentum Solution



CDR Data - Impala

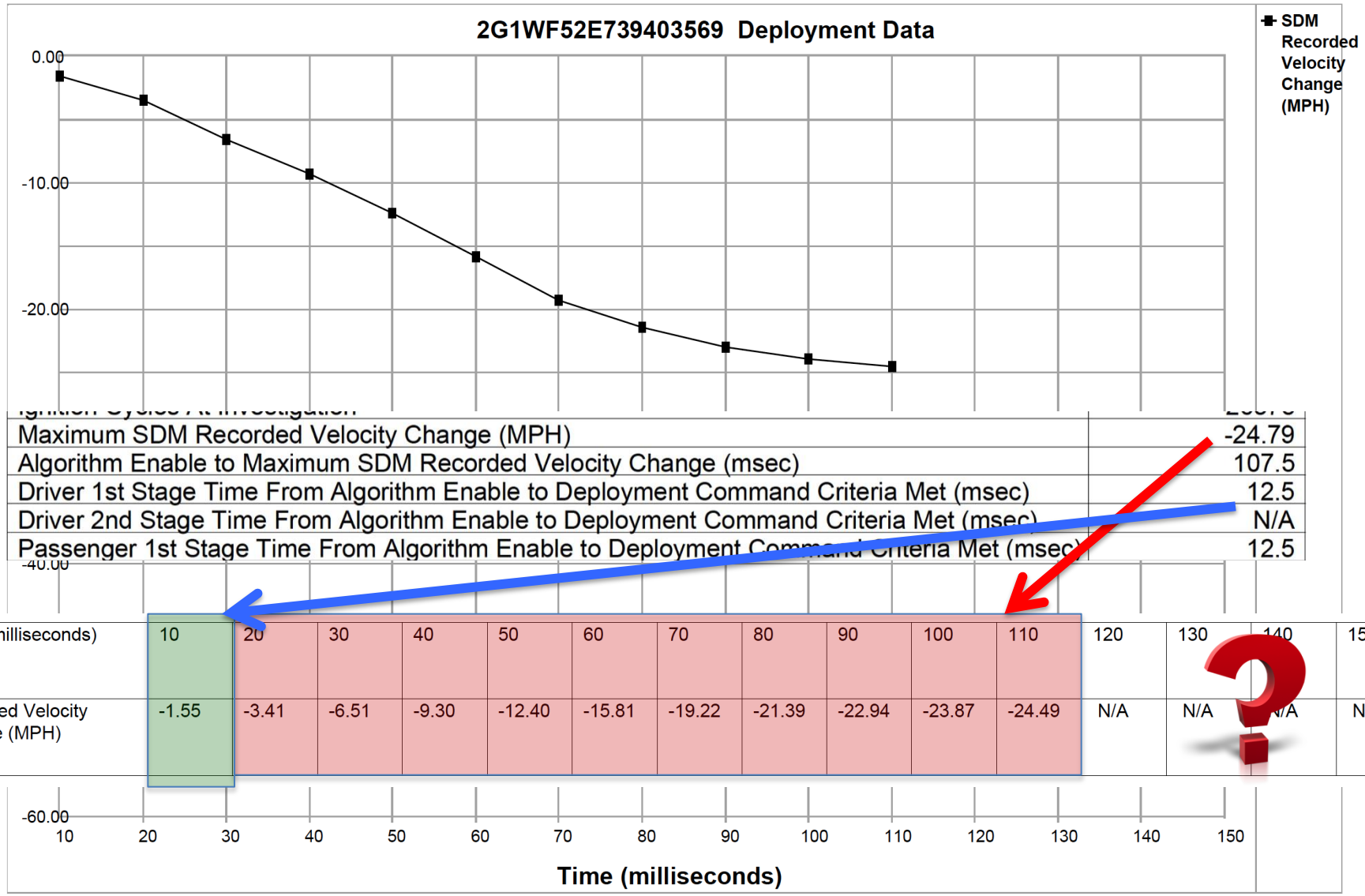
System Status At Deployment

SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	BUCKLED
Ignition Cycles At Deployment	26377
Ignition Cycles At Investigation	26378
Maximum SDM Recorded Velocity Change (MPH)	-24.79
Algorithm Enable to Maximum SDM Recorded Velocity Change (msec)	107.5
Driver 1st Stage Time From Algorithm Enable to Deployment Command Criteria Met (msec)	12.5
Driver 2nd Stage Time From Algorithm Enable to Deployment Command Criteria Met (msec)	N/A
Passenger 1st Stage Time From Algorithm Enable to Deployment Command Criteria Met (msec)	12.5
Passenger 2nd Stage Time From Algorithm Enable to Deployment Command Criteria Met (msec)	N/A
Time Between Non-Deployment And Deployment Events (sec)	N/A
Frontal Deployment Level Event Counter	1
Event Recording Complete	Yes
Multiple Events Associated With This Record	No
One Or More Associated Events Not Recorded	No

Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle
-5	29	768	0
-4	33	832	0
-3	37	704	0
-2	41	832	0
-1	45	768	0

Seconds Before AE	Brake Switch Circuit State
-8	OFF
-7	OFF
-6	OFF
-5	OFF
-4	OFF
-3	OFF
-2	OFF
-1	OFF

CDR Data - Impala



Maximum SDM Recorded Velocity Change (MPH)	-24.79
Algorithm Enable to Maximum SDM Recorded Velocity Change (msec)	107.5
Driver 1st Stage Time From Algorithm Enable to Deployment Command Criteria Met (msec)	12.5
Driver 2nd Stage Time From Algorithm Enable to Deployment Command Criteria Met (msec)	N/A
Passenger 1st Stage Time From Algorithm Enable to Deployment Command Criteria Met (msec)	12.5

Time (milliseconds)	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Recorded Velocity Change (MPH)	-1.55	-3.41	-6.51	-9.30	-12.40	-15.81	-19.22	-21.39	-22.94	-23.87	-24.49	N/A	N/A	N/A	N/A

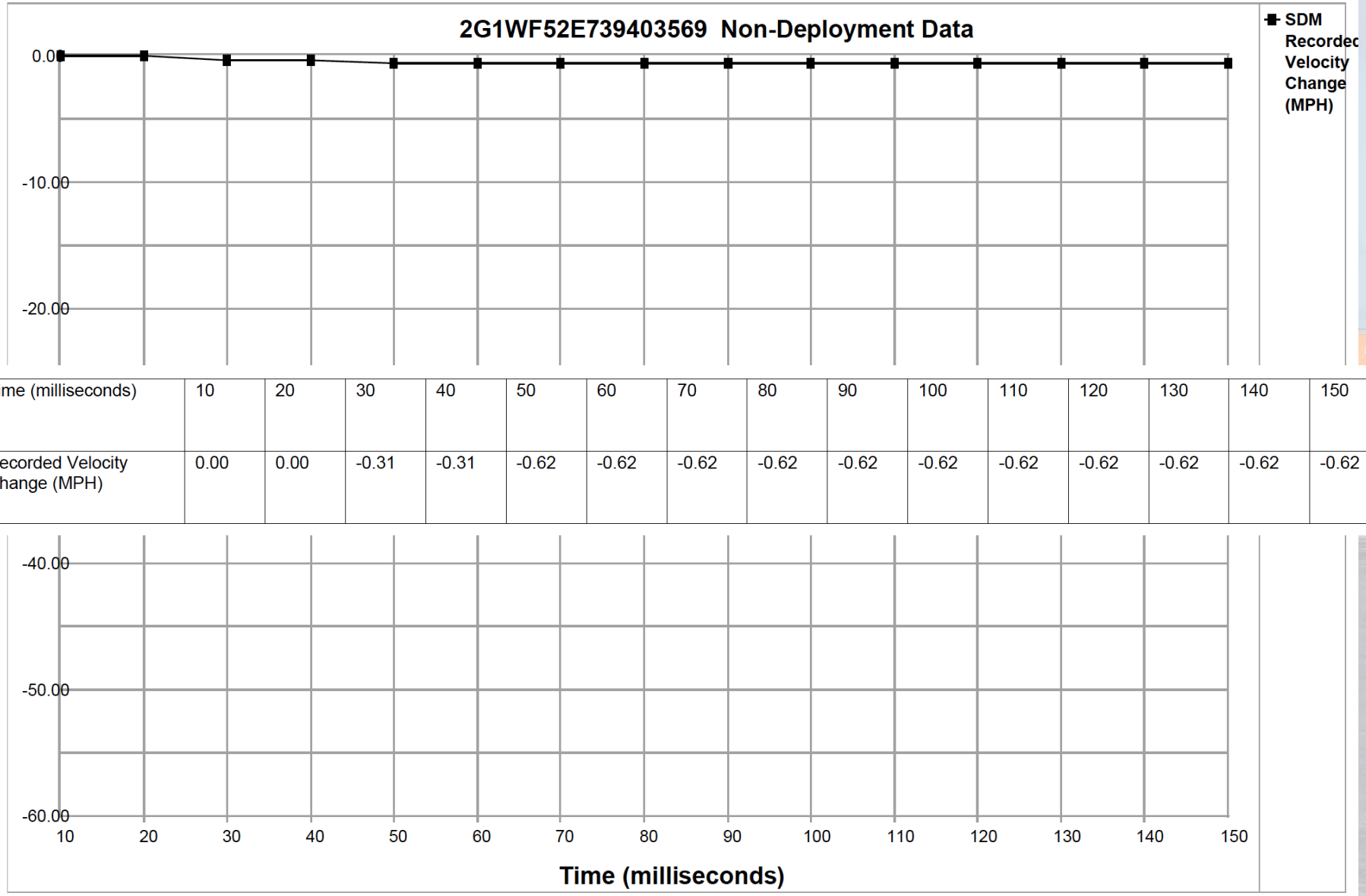
CDR Data - Impala

System Status At Non-Deployment	
SIR Warning Lamp Status	ON
Driver's Belt Switch Circuit Status	BUCKLED
Ignition Cycles At Non-Deployment	26377
Ignition Cycles At Investigation	26378
Maximum SDM Recorded Velocity Change (MPH)	-0.76
Algorithm Enable to Maximum SDM Recorded Velocity Change (msec)	65
Crash Record Locked	No
Event Recording Complete	Yes
Multiple Events Associated With This Record	No
One Or More Associated Events Not Recorded	No

Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle
-5	29	768	0
-4	33	832	0
-3	37	704	0
-2	41	832	0
-1	45	768	0

Seconds Before AE	Brake Switch Circuit State
-8	OFF
-7	OFF
-6	OFF
-5	OFF
-4	OFF
-3	OFF
-2	OFF
-1	OFF

CDR Data - Impala



Time (milliseconds)	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Recorded Velocity Change (MPH)	0.00	0.00	-0.31	-0.31	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62

CDR Data - Malibu

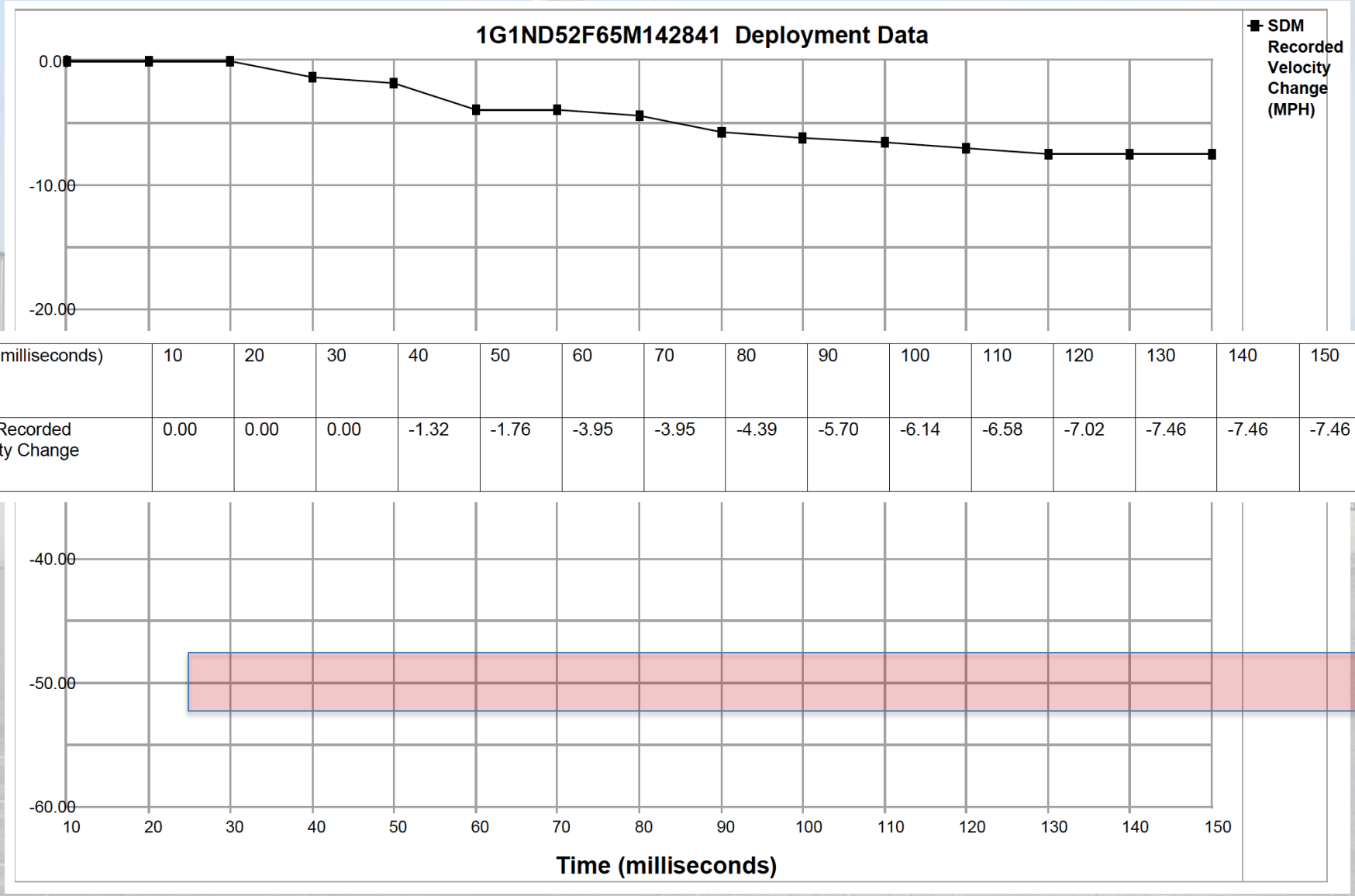
System Status At Deployment

SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	BUCKLED
Passenger SIR Suppression Switch Circuit Status (if equipped)	Air Bag Not Suppressed
Ignition Cycles At Deployment	29108
Ignition Cycles At Investigation	29110
Maximum SDM Recorded Velocity Change (MPH)	-7.69
Algorithm Enable to Maximum SDM Recorded Velocity Change (msec)	140
Time Between this Event and the Previous Event (sec)	0.0
Time From Algorithm Enable to Deployment Command Criteria Met (msec)	47.5

Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle
-5	14	896	0
-4	17	896	0
-3	19	896	0
-2	20	960	0
-1	22	960	0

Seconds Before AE	Brake Switch Circuit State
-8	OFF
-7	OFF
-6	OFF
-5	OFF
-4	OFF
-3	OFF
-2	OFF
-1	OFF

CDR Data - Malibu



Time (milliseconds)	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
SDM Recorded Velocity Change	0.00	0.00	0.00	-1.32	-1.76	-3.95	-3.95	-4.39	-5.70	-6.14	-6.58	-7.02	-7.46	-7.46	-7.46

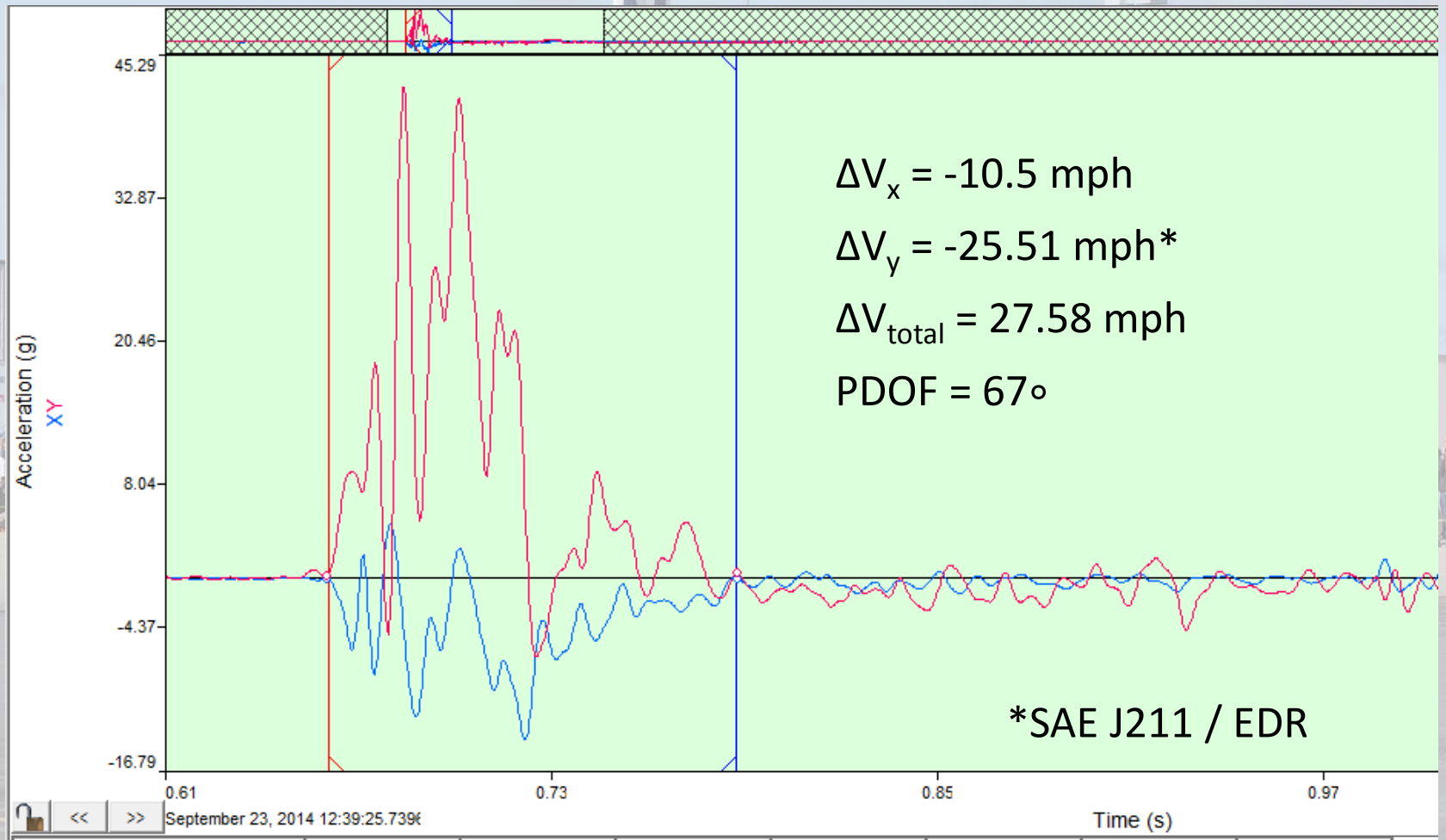
CDR Data - Malibu

System Status At Deployment Level

SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	BUCKLED
Passenger SIR Suppression Switch Circuit Status (if equipped)	Air Bag Not Suppressed
Ignition Cycles At Deployment Level	29108
Ignition Cycles At Investigation	29110
Maximum SDM Recorded Velocity Change (MPH)	-7.69
Algorithm Enable to Maximum SDM Recorded Velocity Change (msec)	140
Time Between this Event and the Previous Event (sec)	N/A
Time From Algorithm Enable to Deployment Command Criteria Met (msec)	47.5

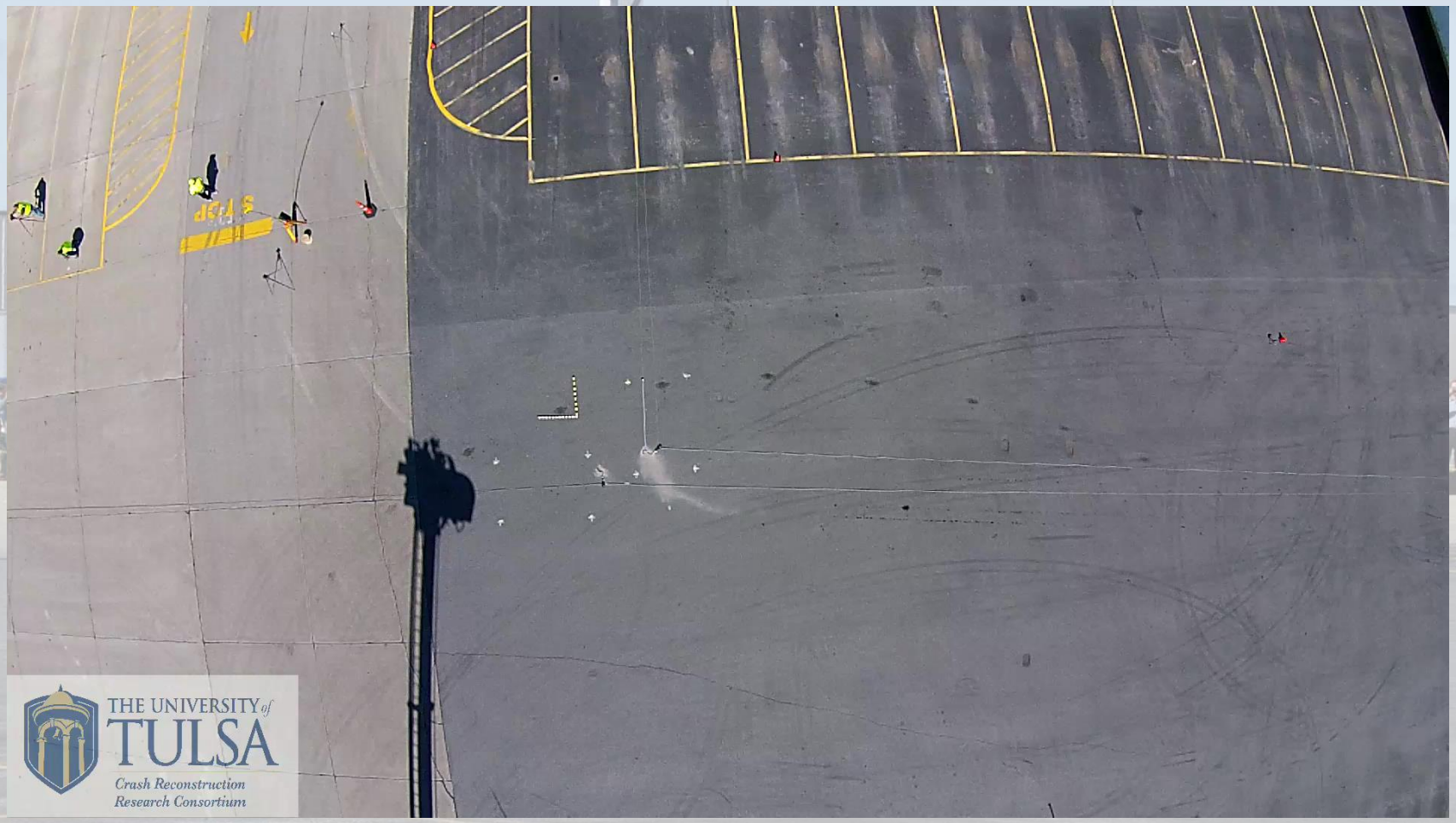
Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle
-5	14	896	0
-4	17	896	0
-3	19	896	0
-2	20	960	0
-1	22	960	0

6DOF – Malibu– Main Impact



Event	Left Cursor Sample Number	Left Value g	Right Cursor Sample Number	Right Value g	Integral miles/hr	Delta Time s	Frequency Hz
f EDR3D #3045A 2:2:X	2041	-0.0505	2428	-0.1171	-10.5	0.126	7.938
f EDR3D #3045A 2:2:Y	2041	0.217	2428	0.3778	25.51	0.126	7.938

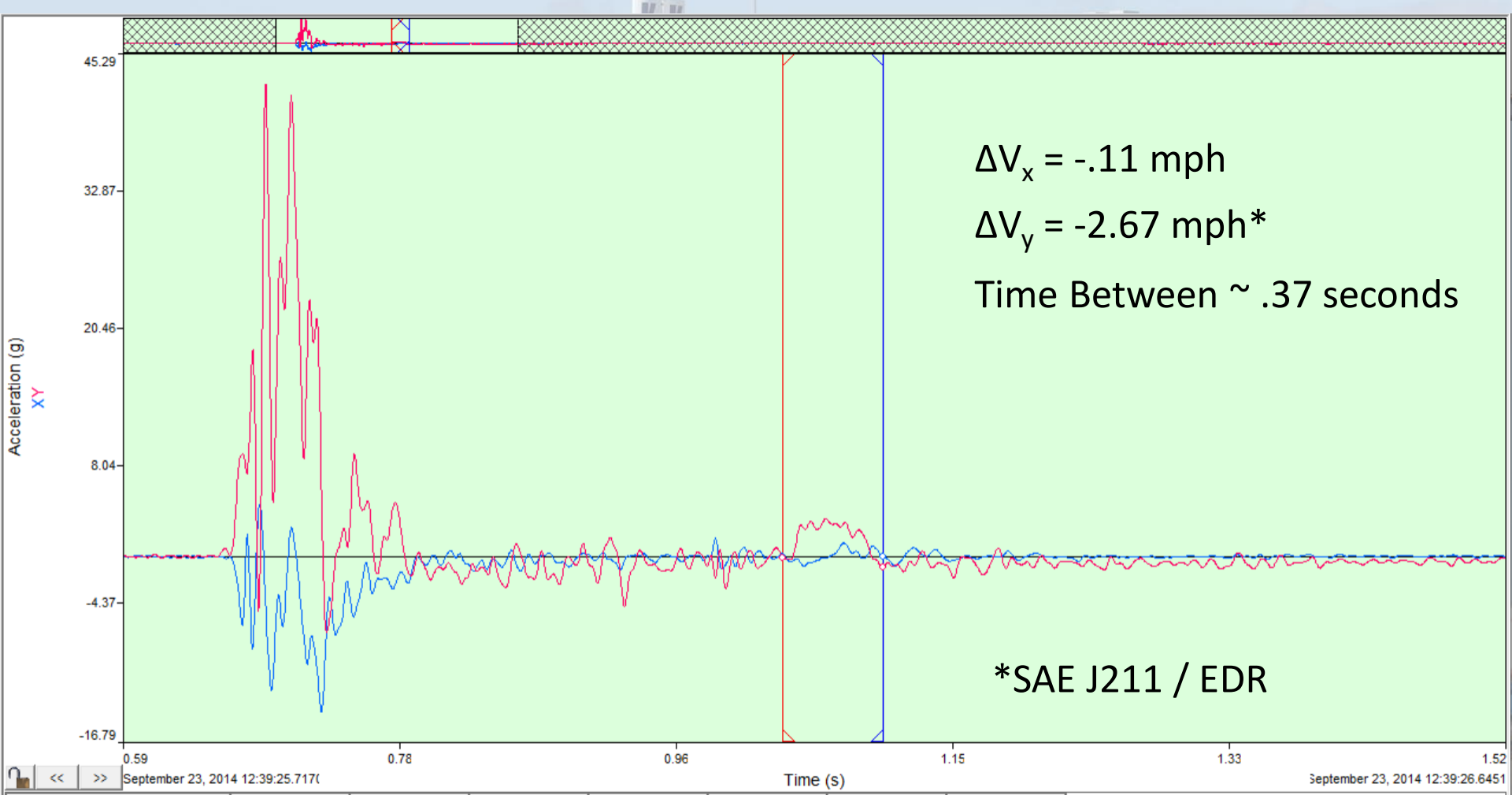
Secondary Contact?



Secondary Contact

Secondary Contact

6DOF – Secondary Impact

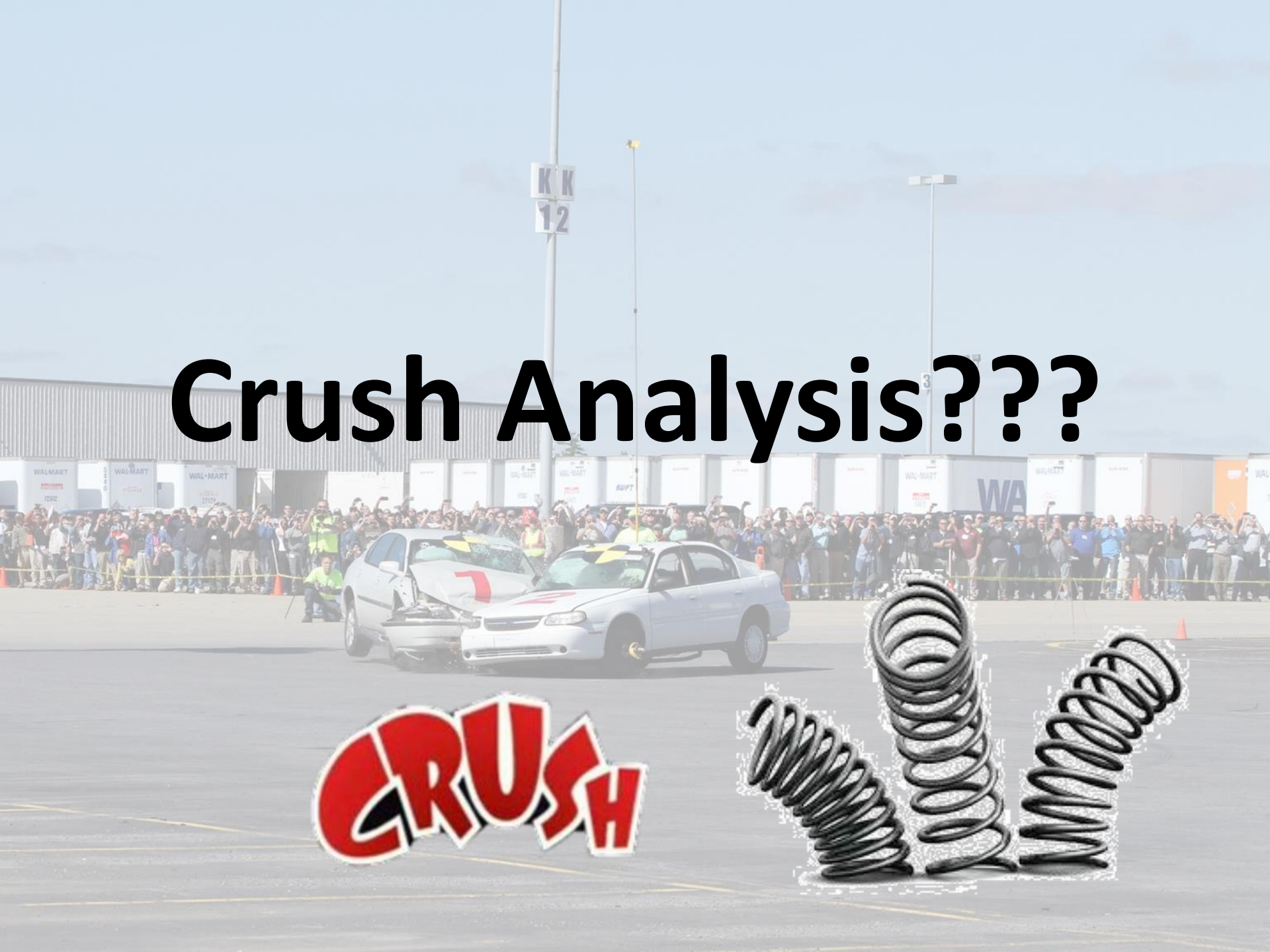


Event	Left Cursor Sample Number	Left Value g	Right Cursor Sample Number	Right Value g	Integral miles/hr	Delta Time s	Frequency Hz
f EDR3D #3045A 2:2:X	3179	0.005499	3384	0.01305	0.1109	0.06673	14.99
f EDR3D #3045A 2:2:Y	3179	-0.09727	3384	-0.9951	2.676	0.06673	14.99

Vbox Sport

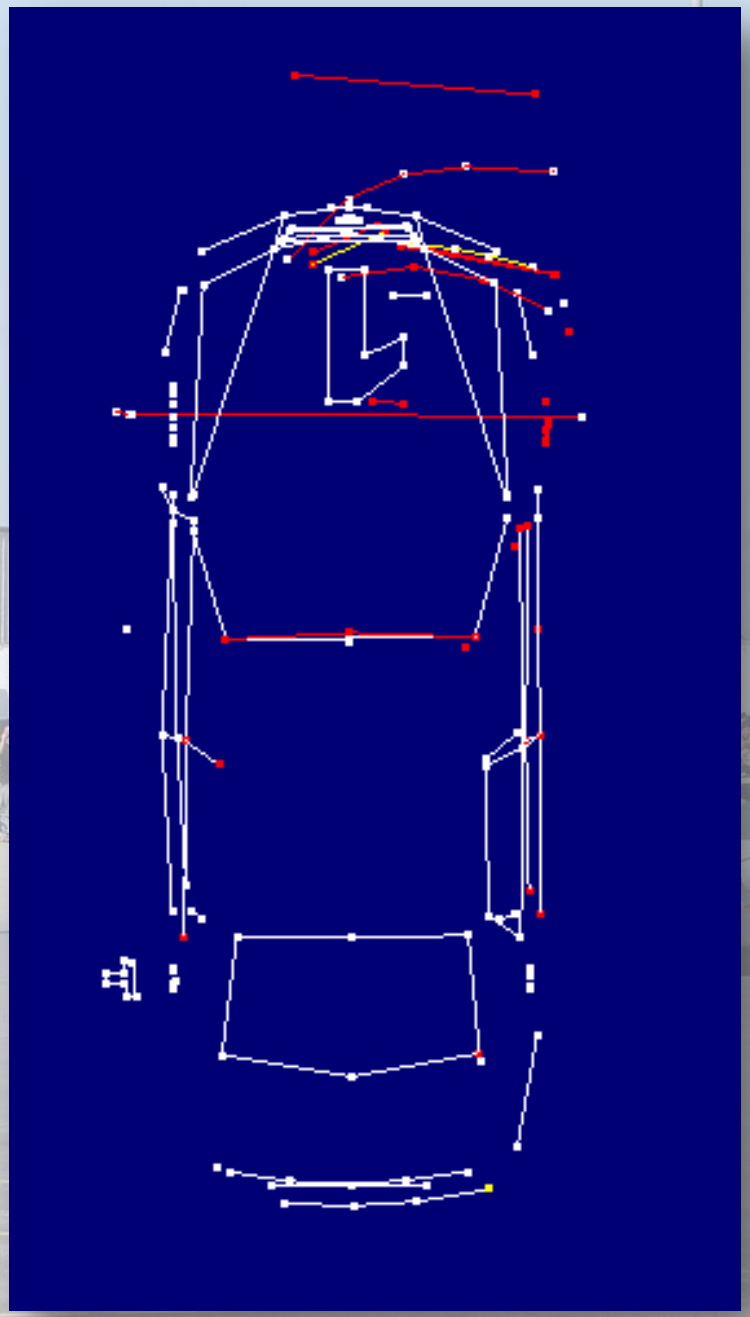
0-62 mph
129.95 mph
Start
Reset
08.13
09.45
0-40 mph
0-50 mph
0-60 mph
VBOX
SPORT
RACELOGIC

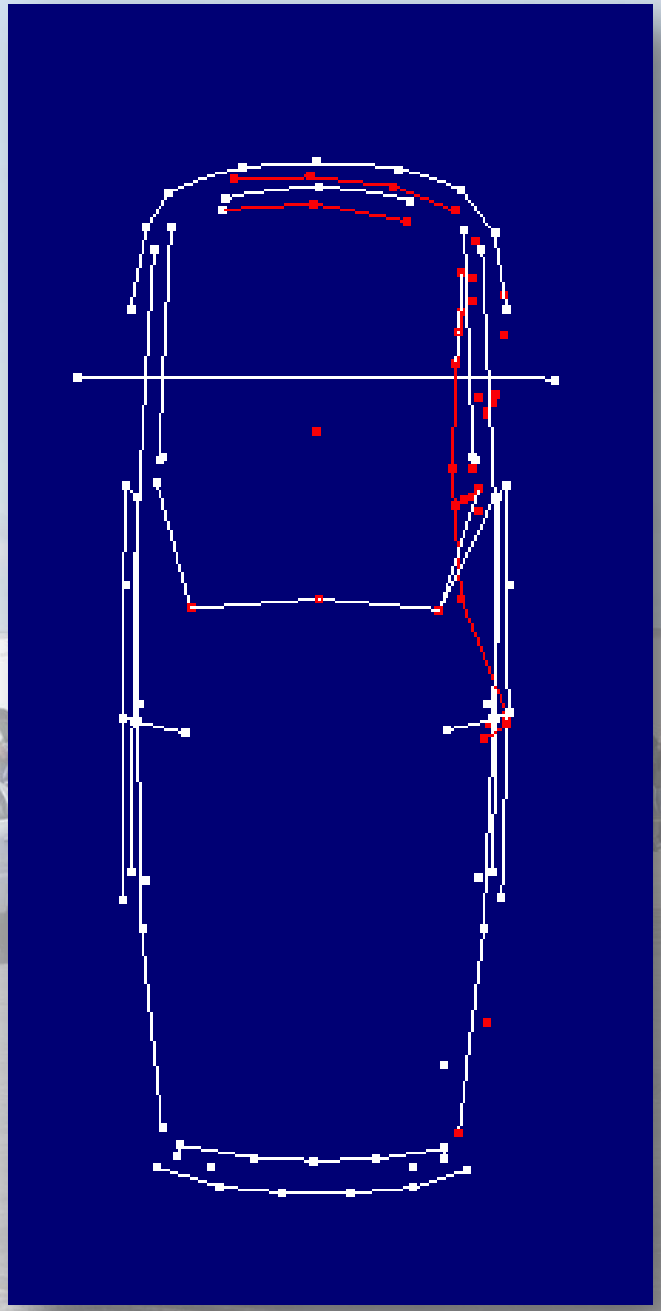
Crush Analysis???

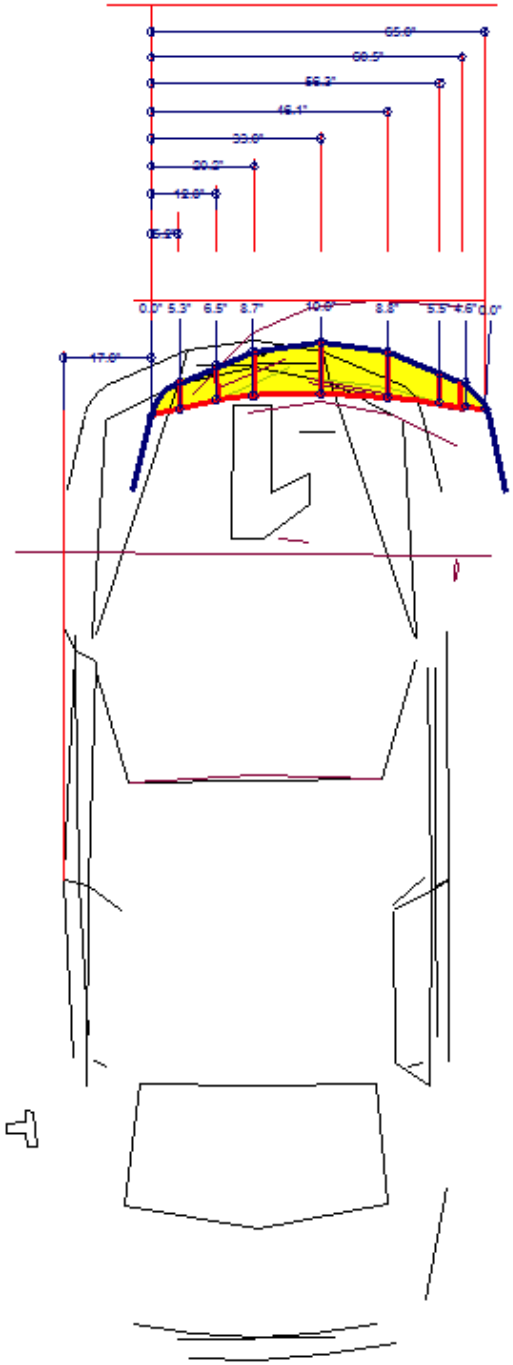


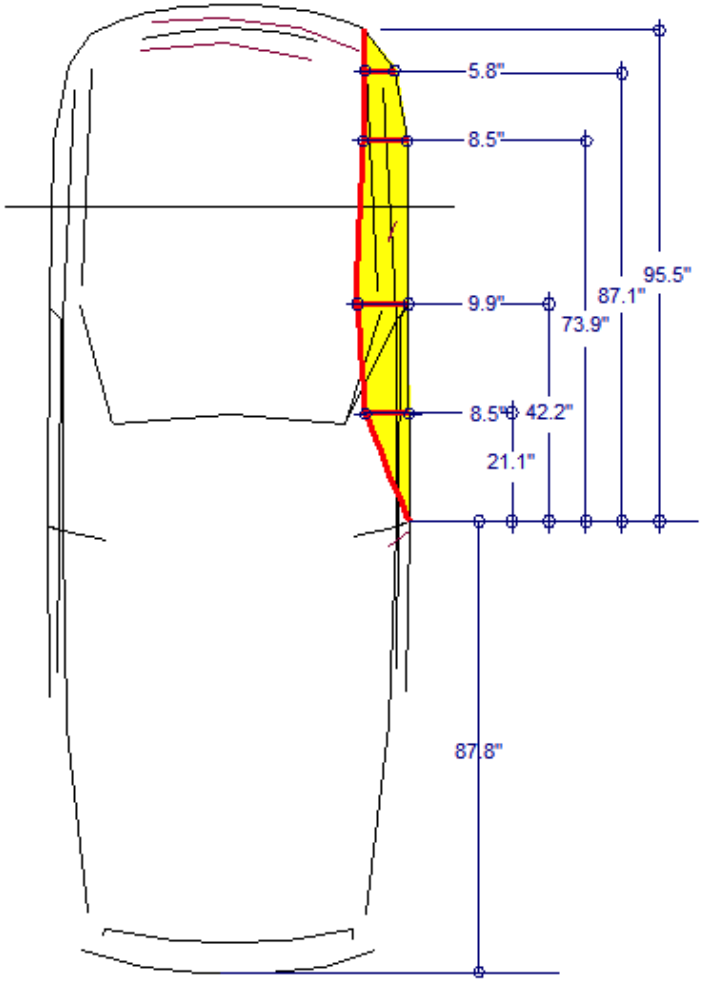
2
CHEVROLET

Damage Profiles Created using Photo Modeler

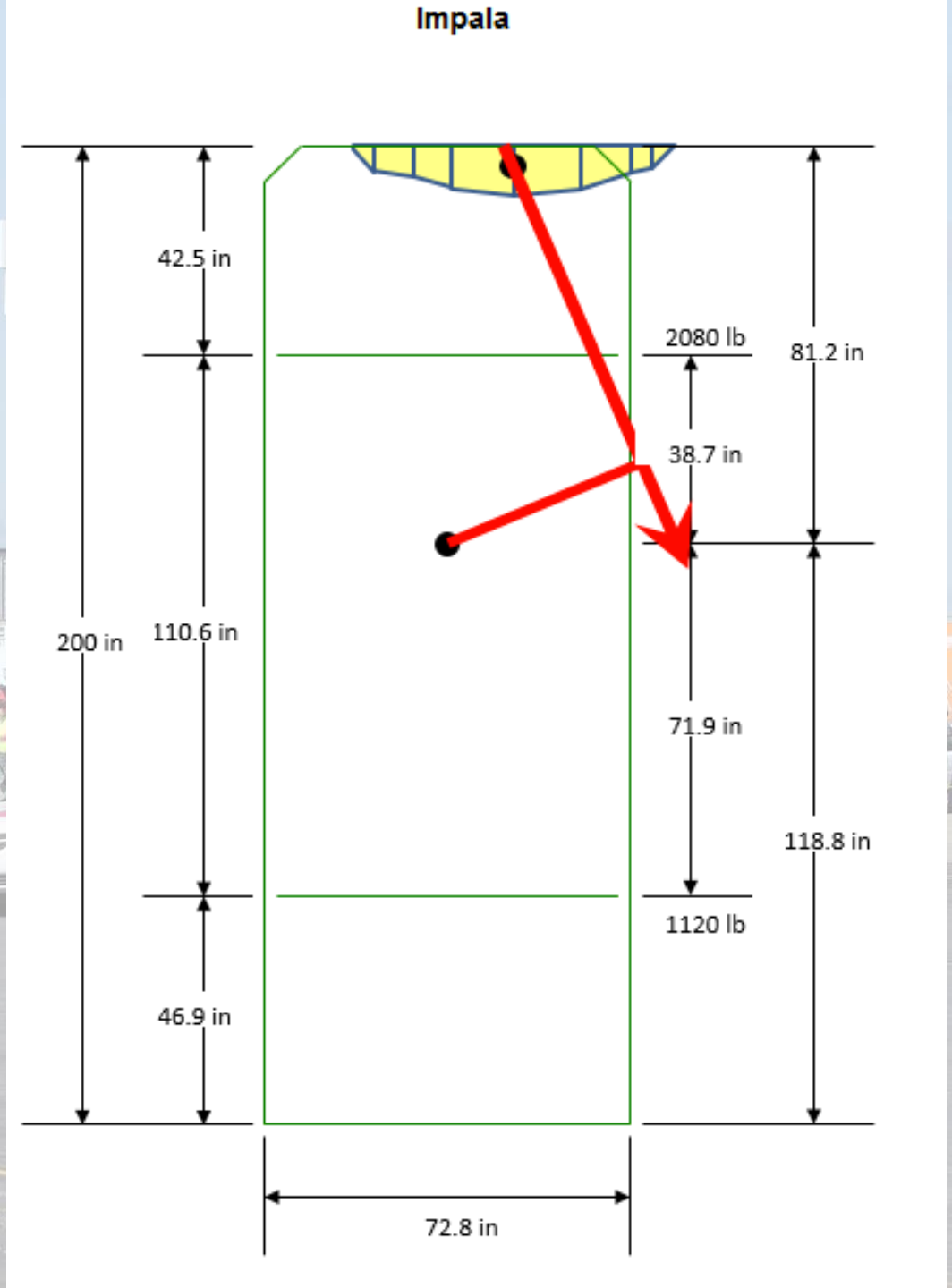




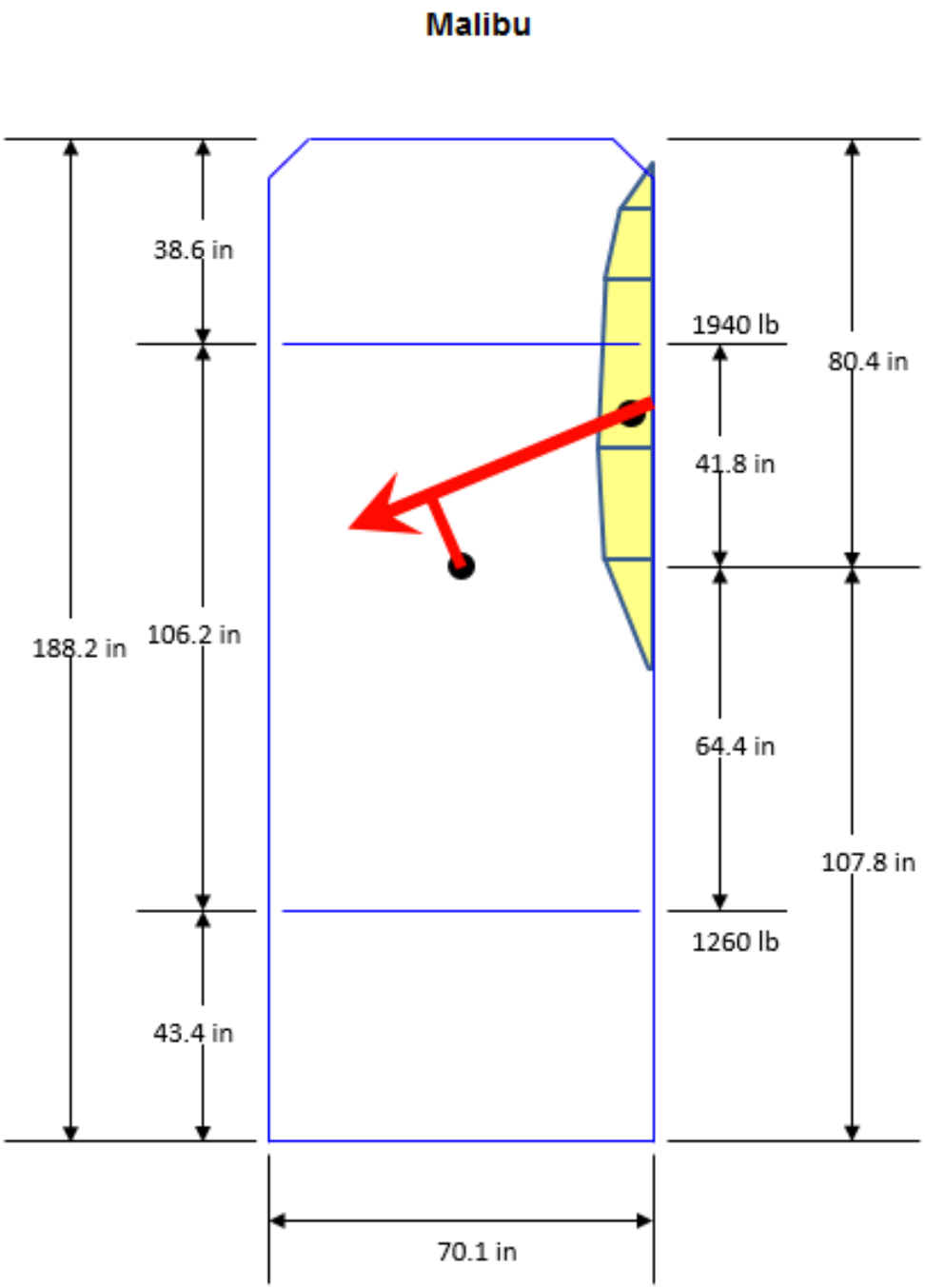

0.0" 5.3" 6.5" 8.7" 10.0" 8.8" 5.5" 4.6" 0.0"
17.0"


5.8"
8.5"
9.9"
8.5"
95.5"
87.1"
73.9"
42.2"
21.1"
87.8"

Impala Damage Profile



Malibu damage Profile



Crash Test: 3798
25 mph Barrier Test
VOLPE
011008
POST
01 CHEVY
IMPALA
TRC
40 KM/H
FRONTAL
011008

Issue

1

Impala Crush

Crash Test Data		Crush Measurements		Distance from c_1	Zone Width
Test Number	3798	c_1	0.0 in	N/A	N/A
Make	Chevrolet	c_2	5.3 in	5.2 in	5.2 in
Model	Impala	c_3	6.5 in	12.8 in	7.6 in
Year	2001	c_4	8.7 in	20.2 in	7.4 in
Δv	27.7 mph	c_5	10.0 in	33.0 in	12.8 in
Average Crush	11.3 in	c_6	8.8 in	46.1 in	13.1 in
b_o	5.0 mph	c_7	5.5 in	56.3 in	10.2 in
Test Weight	3				
Damage Length					

Zone Measurements				
Zone #	Area	X×area	Y×area	Force
1	13.8 in²	24.3 in³	47.8 in³	6,231.4 lb
2	44.8 in²	132.7 in³	409.3 in³	14,858.4 lb
3	56.2 in²	215.2 in³	938.0 in³	17,396.4 lb
4	119.7 in²	560.4 in³	3201.2 in³	35,306.4 lb
5	123.1 in²	579.5 in³	4853.0 in³	36,286.4 lb
6	72.9 in²	265.4 in³	3705.4 in³	22,910.1 lb
				7,380.0 lb
				5,025.9 lb

Crush (damage) Energy — 66,520.7 ft×lb

A stiffness — 535.1 lb/in

B stiffness — 214.3 lb/in²

Force — 145,394.9 lb

Crashed Vehicle	
Contact Width	
PDOF	
Vehicle	
Length	2
Width	
Wheelbase	1
Front Over-hang	
Rear Over-hang	46.9 in
Total Weight	3,200.0 lb
Front axle weight	2,080.0 lb
Rear Axle weight	1,120.0 lb
Front/Rear %	65% / 35%

Centroid Y – Offset Measurements	
Distance From c_1 Measurement	*32.5 in*
Offset from Damage Center	*0. in*
Offset from Center of Gravity	*13.1 in*
+ = right or rear of cg, - = left or forward of cg	

Damage Plain Moment Arm Information	
Damage Plain Side	*Front*
Damage Plain pdof (Energy & Force Calculations)	*23.0°*
Moment Arm Distance	*42.3 in*

Malibu Crush

Crashed Vehicle Data	
Contact Width	95.5 in
b_o	5.0 mph
PDOF	67.0°
Vehicle	Malibu
Length	188.2 in
Width	70.1 in
Wheelbase	106.2 in
Front Over-hang	38.6 in
Rear Over-hang	43.4 in
Total Weight	3,200.0 lb
Front axle weight	1,940.0 lb
Rear Axle weight	1,260.0 lb
Front/Rear %	61% / 39%

Average Crush of Computer Model	9.68 in

	Crush Measurements	Distance from c_1	Zone Width
c_1	0.0 in	N/A	N/A
c_2	8.8 in	21.1 in	21.1 in
c_3	9.9 in	42.2 in	21.1 in
c_4	8.5 in	73.9 in	31.7 in
c_5	5.8 in	87.1 in	13.2 in
c_6	0.0 in	95.5 in	8.4 in

Zone Measurements

Zone #	Area	X×area	Y×area	Force
1	92.8 in²	272.3 in³	1305.9 in³	22,163.1 lb
2	197.3 in²	923.4 in³	6284.9 in³	38,961.6 lb
3	291.6 in²	1344.1 in³	16812.5 in³	57,770.0 lb
4	94.4 in²	341.4 in³	7558.4 in³	19,703.4 lb
5	24.4 in²	47.1 in³	2190.0 in³	6,796.7 lb

Crush (damage) Energy — 67,528.0 ft×lb

A stiffness — 315.5 lb/in

B stiffness — 148.1 lb/in²

Force — 145,394.9 lb

,528.0 ft×lb
5.5 lb/in
B stiffness — 148.1 lb/in²
Force — 145,394.9 lb

Centroid Depth from Damage Plain	4.2 in
Distance From Center of Gravity	30.9 in

Centroid Y – Offset Measurements	
Distance From c_1 Measurement	48.8 in
Offset from Damage Center	1. in
Offset from Center of Gravity	28.8 in

+ = right or rear of cg, - = left or forward of cg

Damage Plain Moment Arm Information	
Damage Plain Side	Right
Damage Plain pdof (Energy & Force Calculations)	23.0°
Moment Arm Distance	-14.4 in

Δv Calculations

ebs/bev	36.6 fps 24.9 mph
ΔV	**31.7 fps** **21.6 mph**

ebs/bev	36.8 fps 25.1 mph
ΔV	**31.7 fps** **21.6 mph**

P_1 – Vehicle #1 Impact Momentum	127,237.3 mph - lbs @	0.00 °	39.8 mph
P_2 _ Vehicle #2 Impact Momentum	59,419.9 mph - lbs @	90.00 °	18.6 mph
P_1' - Vehicle #1 Post Impact Momentum	69,112.8 mph - lbs @	23.00 °	21.6 mph
P_2' - Vehicle #2 Post Impact Momentum	71,400.9 mph - lbs @	27.00 °	22.3 mph
Total Momentum	140,428.1 mph - lbs @	25.03 °	
ΔP_1 (V_1— Impulse Vector)	69,112.8 mph - lbs @	157.00 °	21.6 mph
ΔP_2 (V_2— Impulse Vector)	69,112.8 mph - lbs @	337.00 °	21.6 mph

Vehicle #1 PDOF: -23.00° Vehicle #1 Weight 3,200.0 lbs

Impala Impact Speed: 39.8 mph

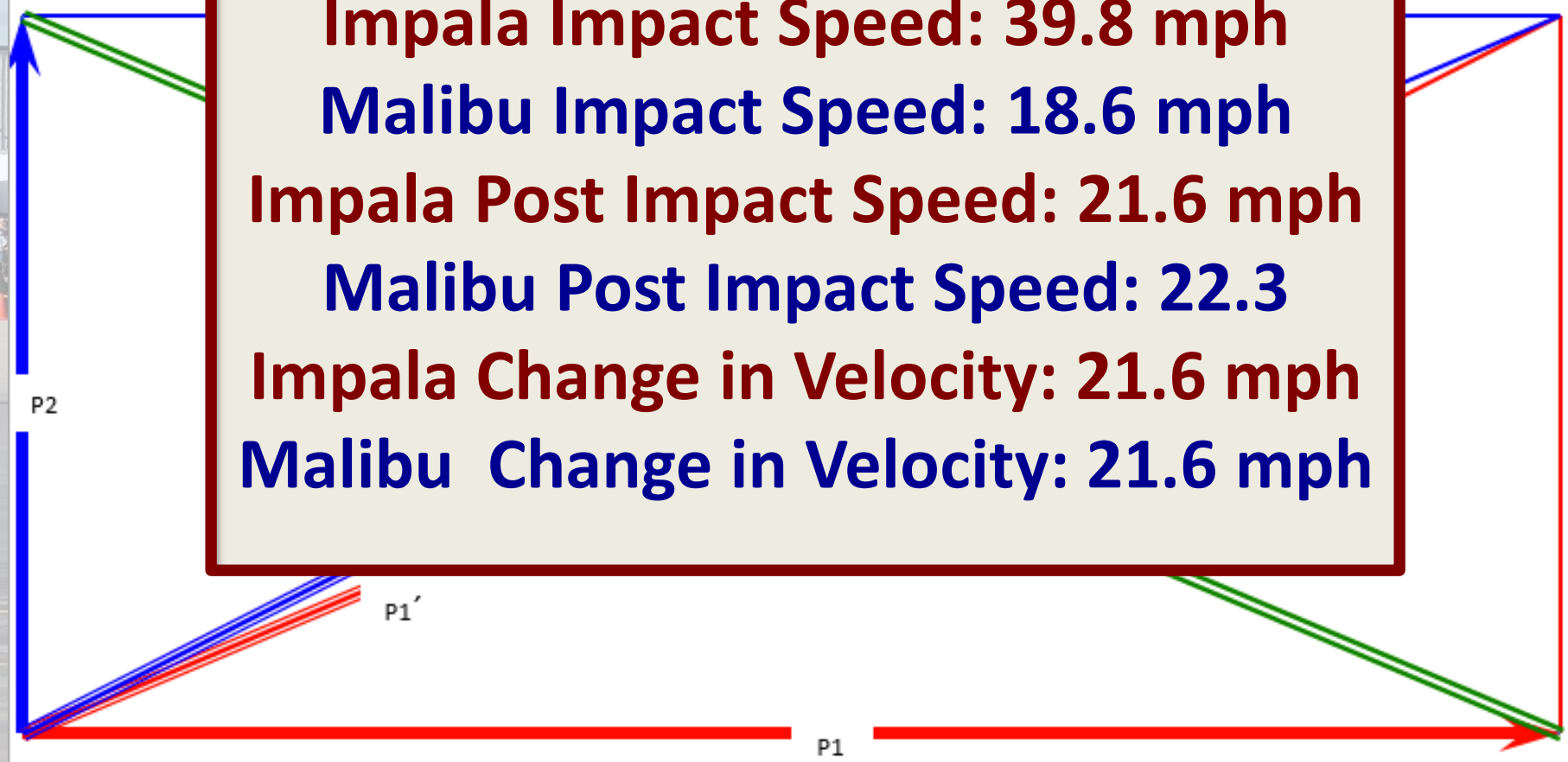
Malibu Impact Speed: 18.6 mph

Impala Post Impact Speed: 21.6 mph

Malibu Post Impact Speed: 22.3

Impala Change in Velocity: 21.6 mph

Malibu Change in Velocity: 21.6 mph



Crash Test #2

1993 Peterbilt vs.

1999 Grand Am

1993 Peterbilt 379 Conventional Cab 6X4 Tractor

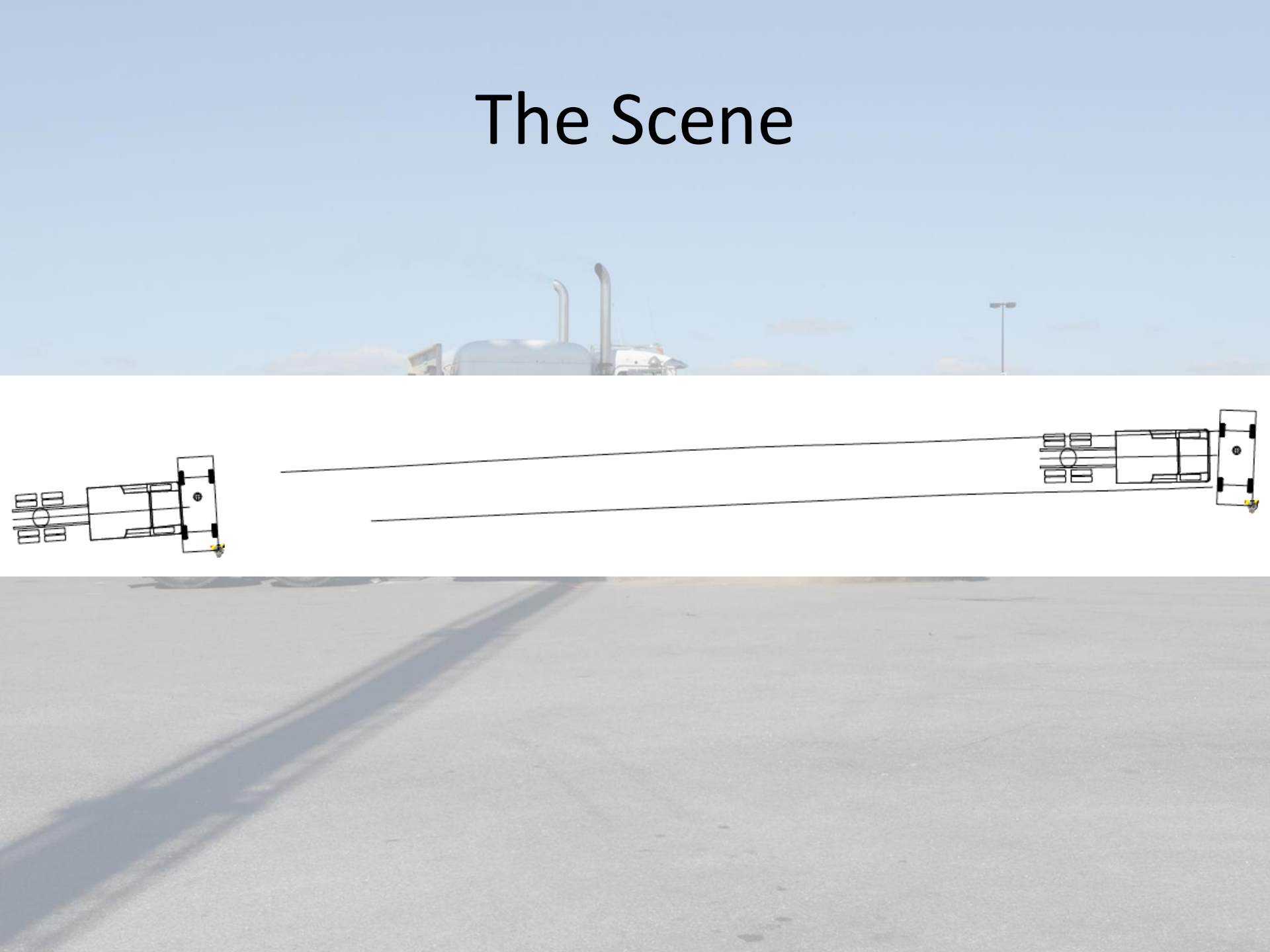
Measured Weight 19,000 Pounds

1999 Pontiac Grand Am, 2 door

Measured Weight 3000 Lbs

The Scene

The Scene



Video

Con-way
FedEx
Intermodal
THE UNIVERSITY of
TULSA
Crash Reconstruction
Research Consortium

Video

Video

THE UNIVERSITY of
TULSA
Crash Reconstruction
Research Consortium

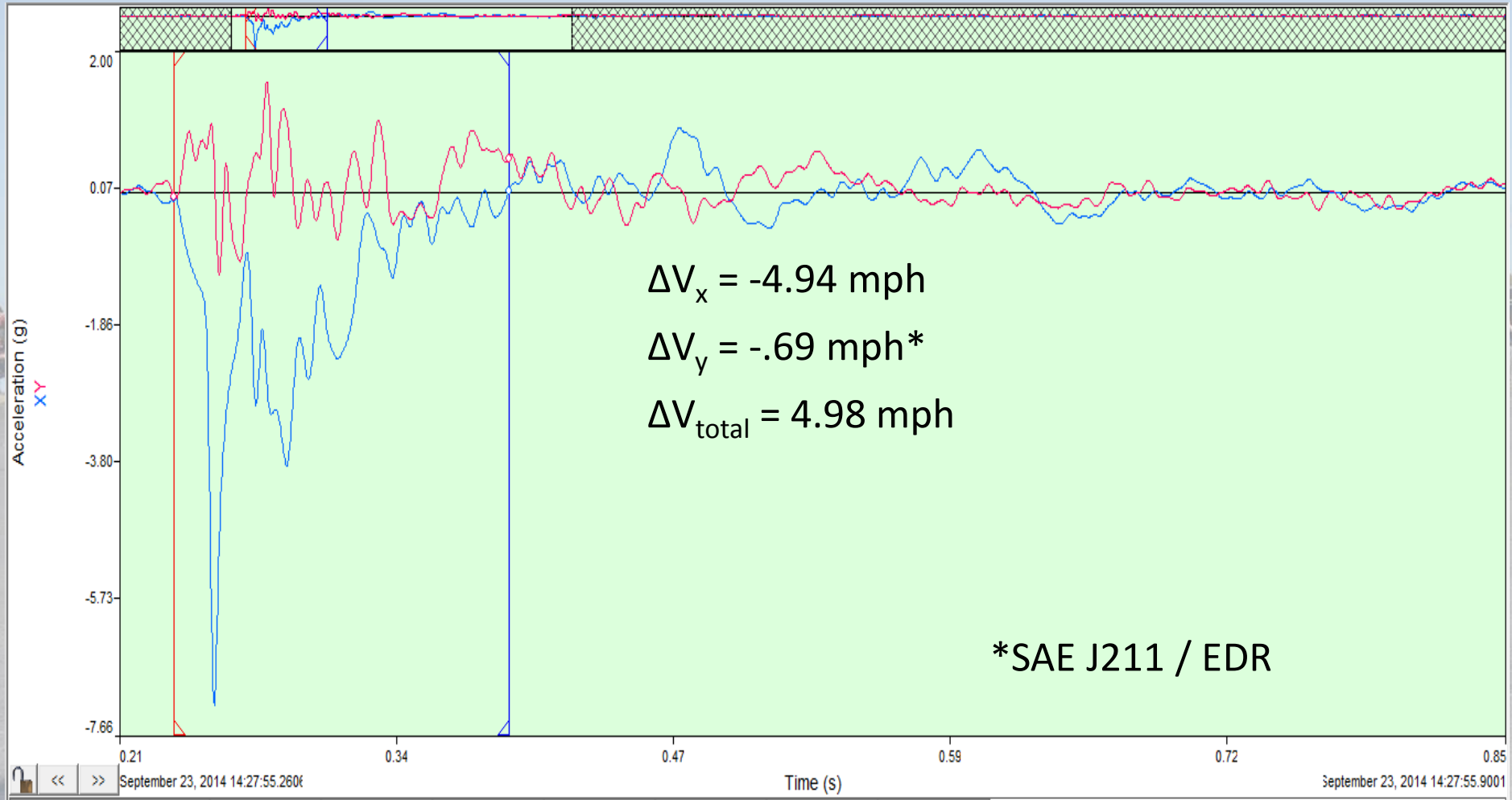
Video

100
125
75
50
25
VIDEO VBOX
TIME
00:00:00.10
0
KM/H
LAT G
-0.00
LONG G
+0.00

Crash Facts

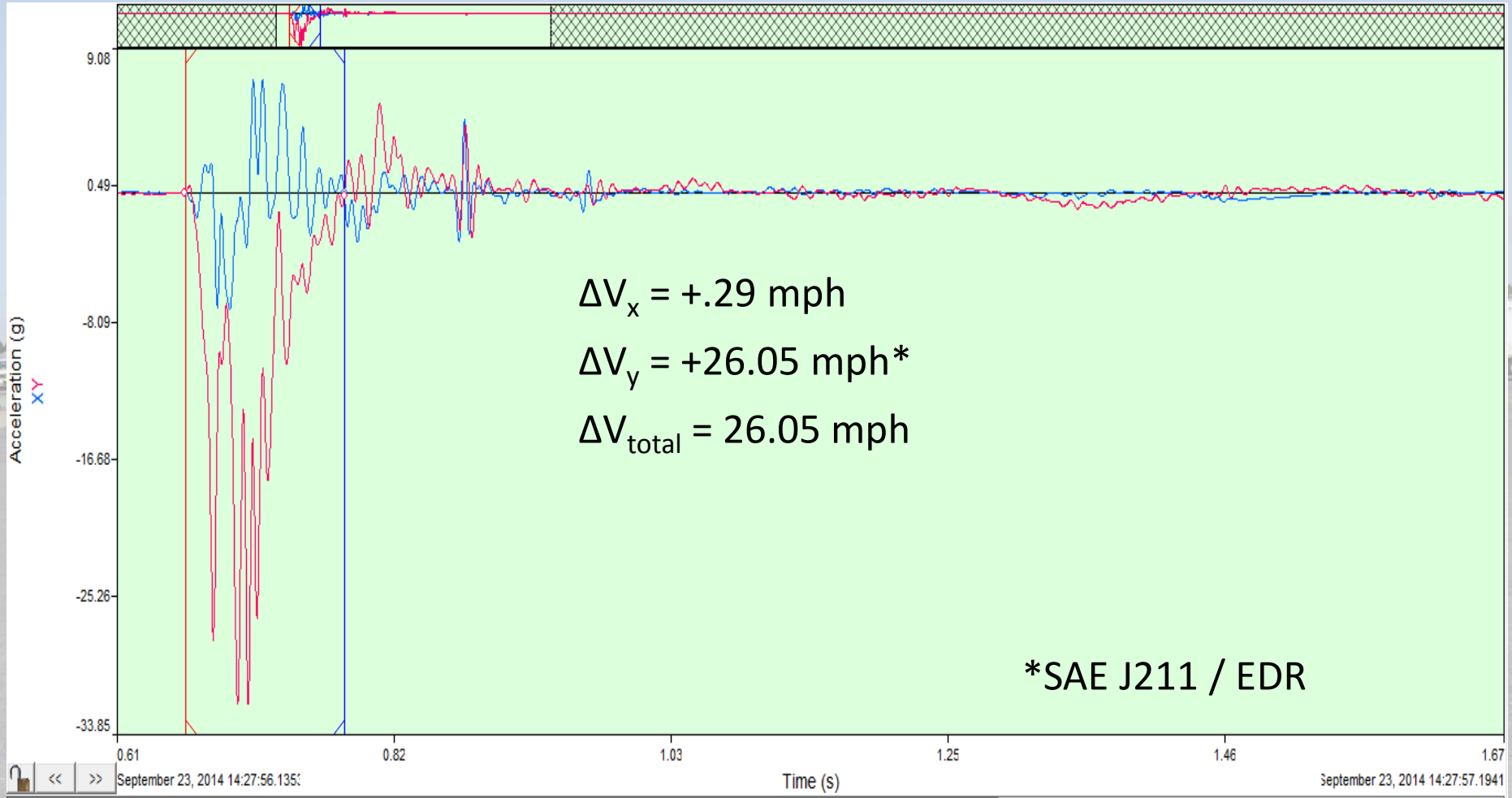
- Central Collision—no need to consider rotation with Effective Mass Ratio
- Delta V of the car was 26 mph
- Measured impact speed was 28 mph

Test #2 - Bullet



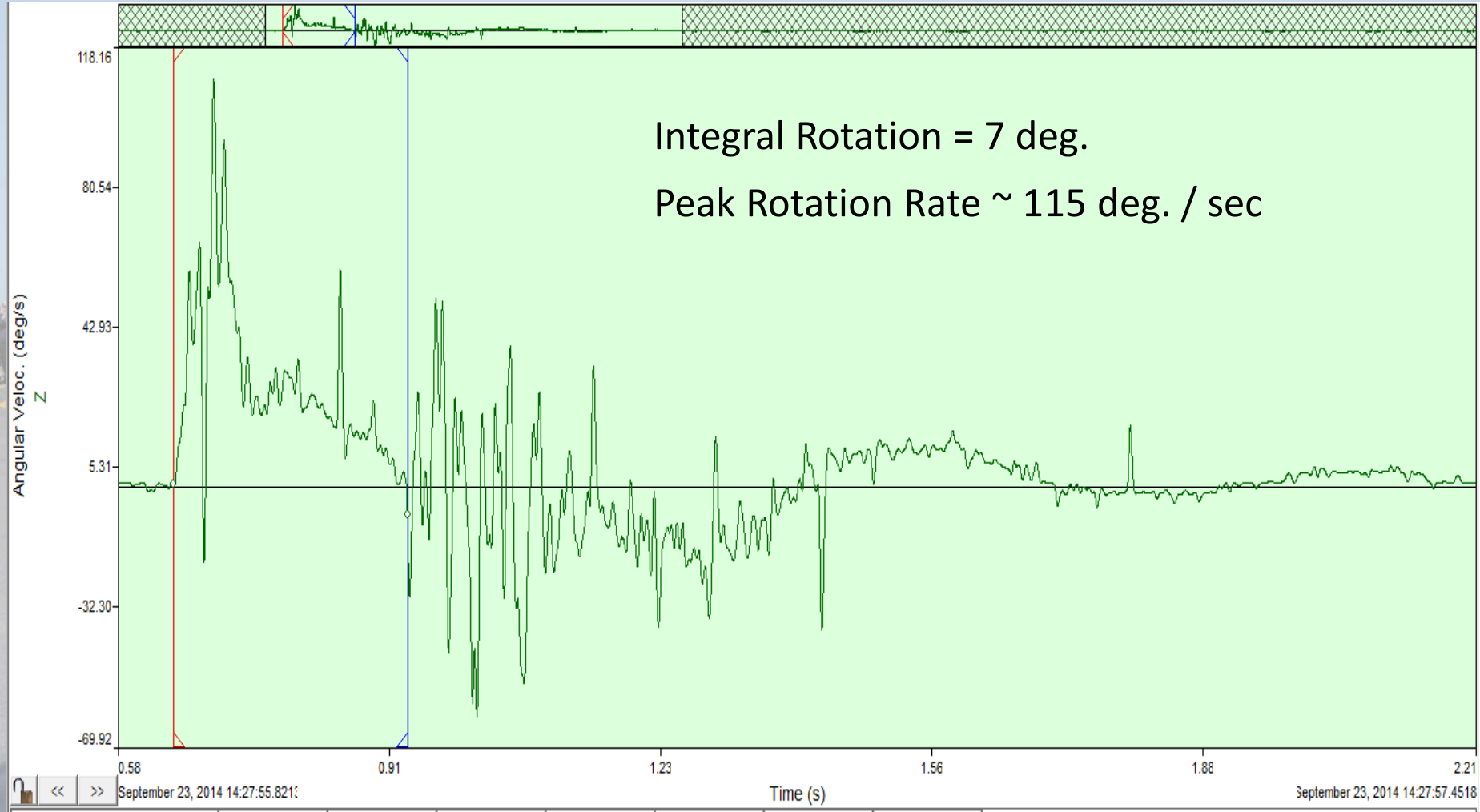
Event	Left Cursor Sample Number	Left Value g	Right Cursor Sample Number	Right Value g	Integral miles/hr	Delta Time s	Frequency Hz
f EDR3C #1951 1:3:X	727	-0.07176	1201	0.01378	-4.941	0.1543	6.481
f EDR3C #1951 1:3:Y	727	-0.06858	1201	0.4878	0.6993	0.1543	6.481

Crash 2 – Grand Am CG 6DOF - A



Event	Left Cursor Sample Number	Left Value g	Right Cursor Sample Number	Right Value g	Integral miles/hr	Delta Time s	Frequency Hz
f EDR3D #3045A 1:1:X	2034	0.05693	2408	-0.02049	0.2993	0.1217	8.214
f EDR3D #3045A 1:1:Y	2034	0.04948	2408	-0.1407	-26.05	0.1217	8.214

Crash 2 – Grand Am CG 6DOF - B



Event	Left Cursor Sample Number	Left Value deg/s	Right Cursor Sample Number	Right Value deg/s	Integral deg	Delta Time s	Frequency Hz
f EDR3D #3045B 1:1:Z	1990	0.7908	2851	-7.345	7.697	0.2803	3.568

Closing Speed Calculation

Calculate the delta-V of the truck:

$$\Delta v_{truck} = \frac{\Delta v_{car} w_{car}}{w_{truck}} = \frac{(26)(3000)}{19000} = 4.1 \text{ mi/h}$$

Calculate the closing speed (impact speed)

$$v_c = |\Delta v_1| + |\Delta v_2| = 26 + 4.1 = 30.1 \text{ mi/h}$$

- The calculated speed is a bit higher than the measured impact speed of 28 mph. Why?
- Answer: Restitution

Considering Restitution:

$$v_c = \left(\frac{1}{1+e}\right)\left(|\Delta v_1| + |\Delta v_2|\right) = \left(\frac{1}{1+.1}\right)(26 + 4.1) = 27.3 \text{ mi/h}$$

Crash Test #3

1993 Peterbilt vs.

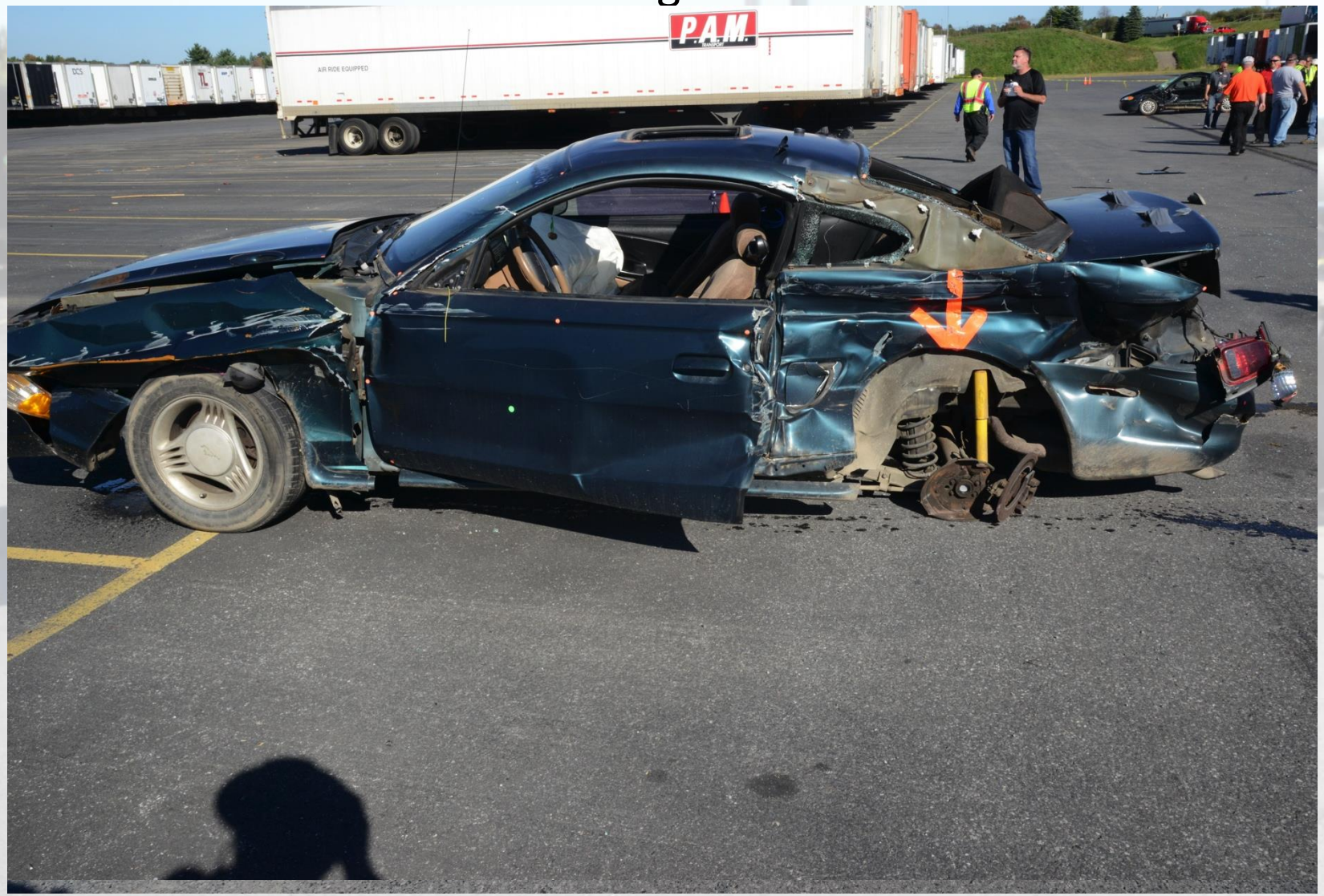
1994 Mustang

1993 Peterbilt 379 Conventional Cab 6X4 Tractor

Measured Weight 19,000 Pounds

1994 Ford Mustang, 2 door

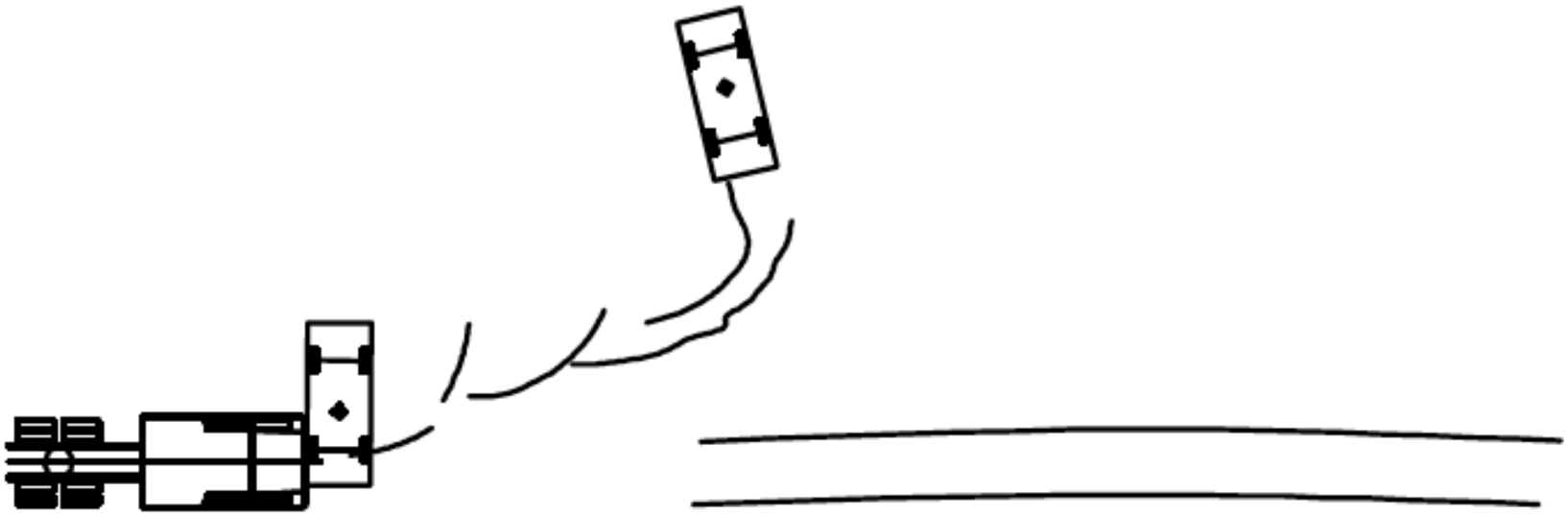
Measured Weight 3060 Lbs



The Scene

The Scene

The Scene



Video

Con-way
FedEx
intermodal
THE UNIVERSITY of
TULSA
Crash Reconstruction
Research Consortium

Video

Video

THE UNIVERSITY of
TULSA
Crash Reconstruction
Research Consortium

Video

100
125
75
50
25
VIDEO VBOX
TIME
00:00:00.10
0
KM/H
LAT G
-0.00
LONG G
+0.00

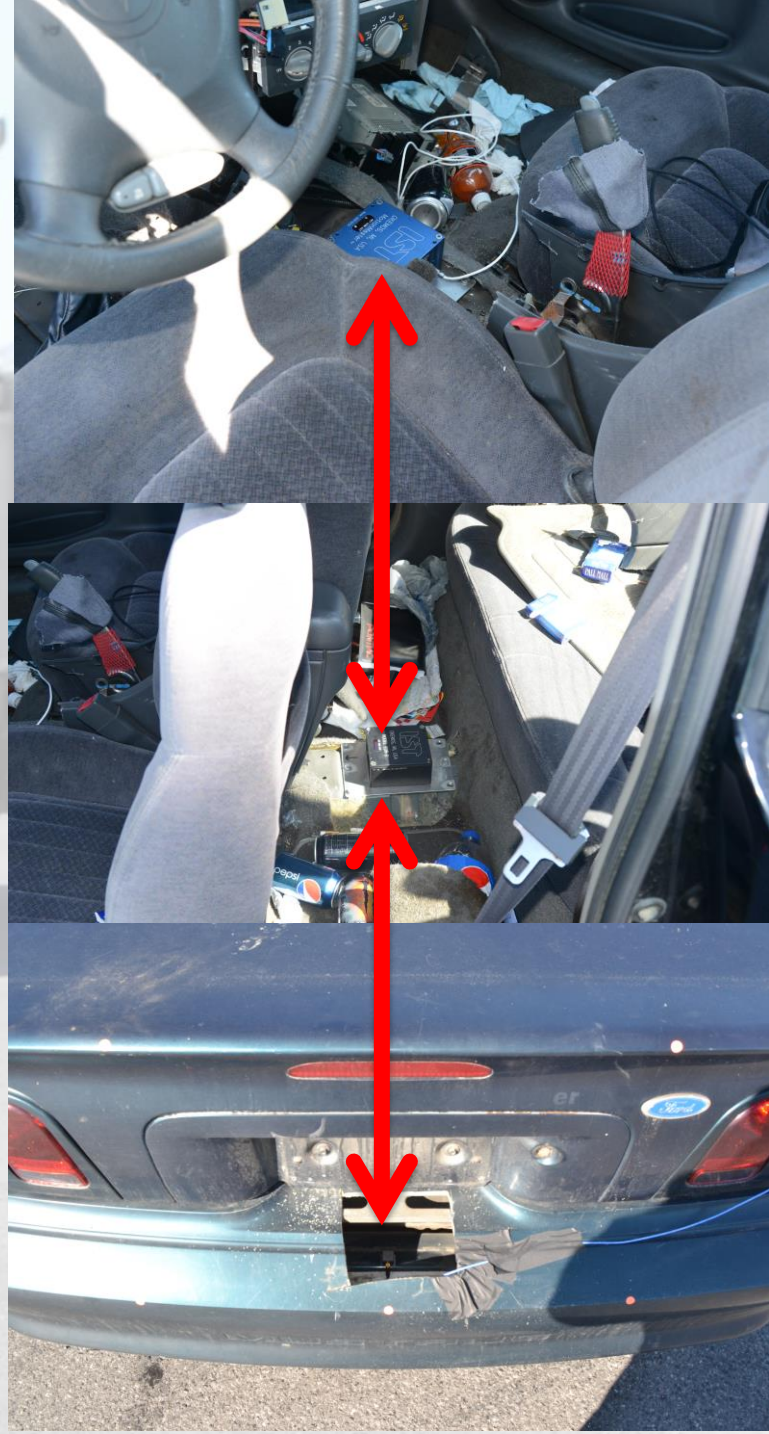
Video

Crash Facts

- Non-Central Collision—need to consider rotation with Effective Mass Ratio
- Long Delta-V = 2.687 mph
- Lateral Delta-V = 16.410 mph
- Measured impact speed was 33 to 34 mph
- From instrumentation:
  - 316 deg. Rotation
  - Max rate was 408 deg./sec

IST Data

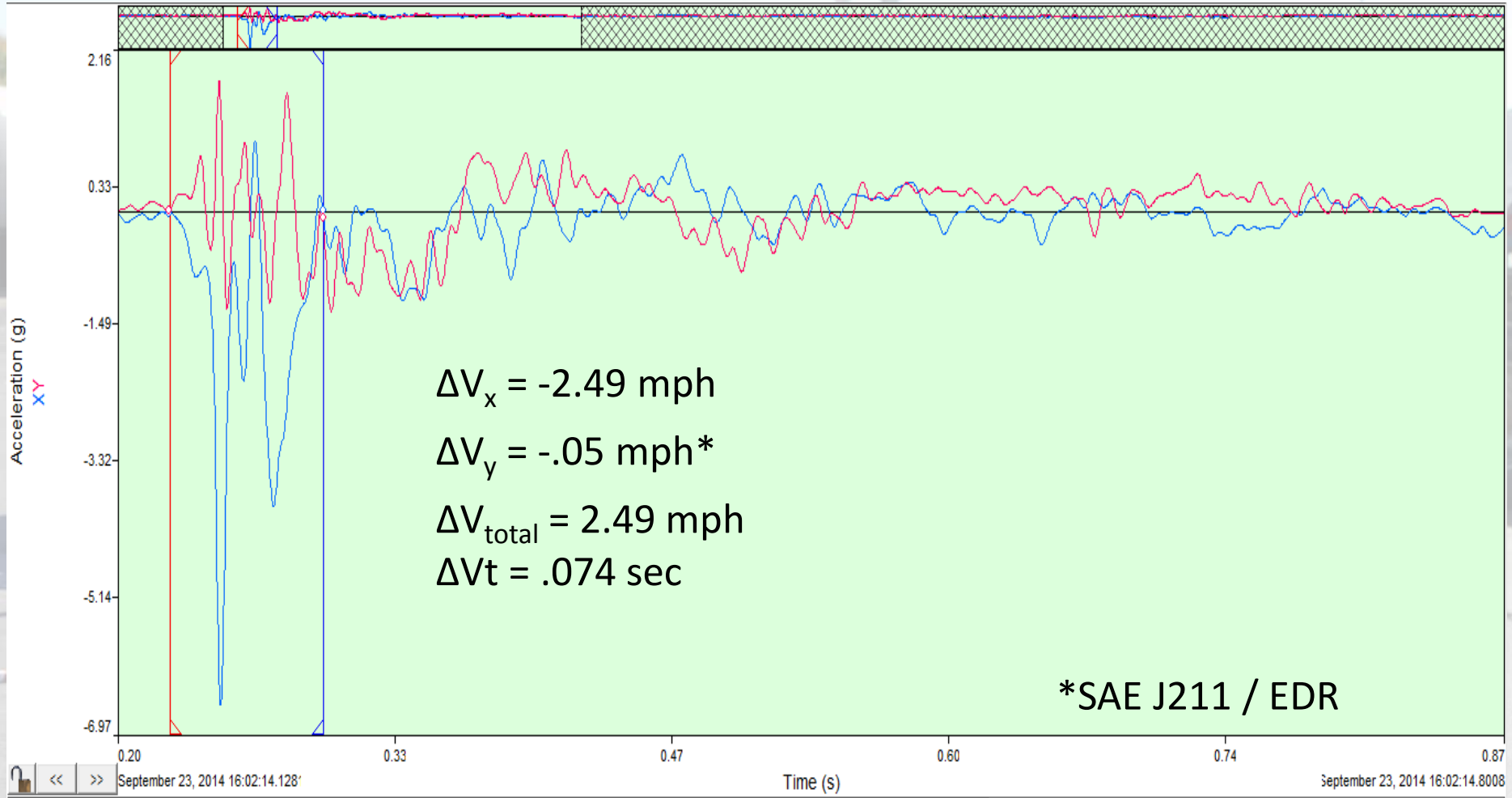
- Multiple Accelerometers
  - 6DOF was at ~CG (longitudinal)
  - Middle IST was ~1.9 feet read of 6DOF IST
  - Rear IST on bumper bar near rear-most point of vehicle



IST Data

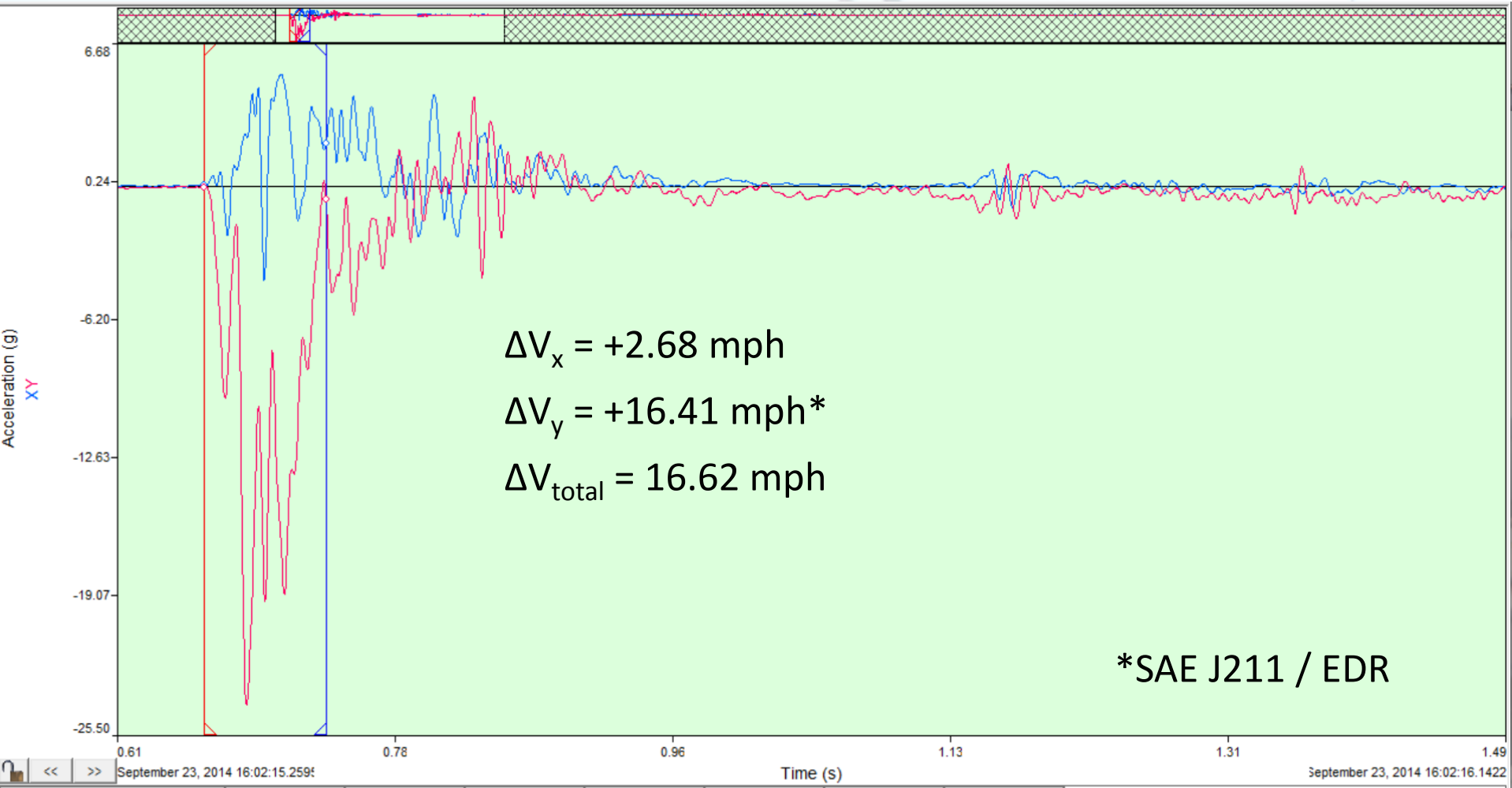
- Different Δ's at different locations in the vehicle?
  - Forward IST:
    - 16.62 mph
  - Middle IST:
    - 27.58 mph
  - Rear IST
    - No reliable data due to extreme clipping / saturation of 50g rated accelerometer!!

Test #3 – Bullet



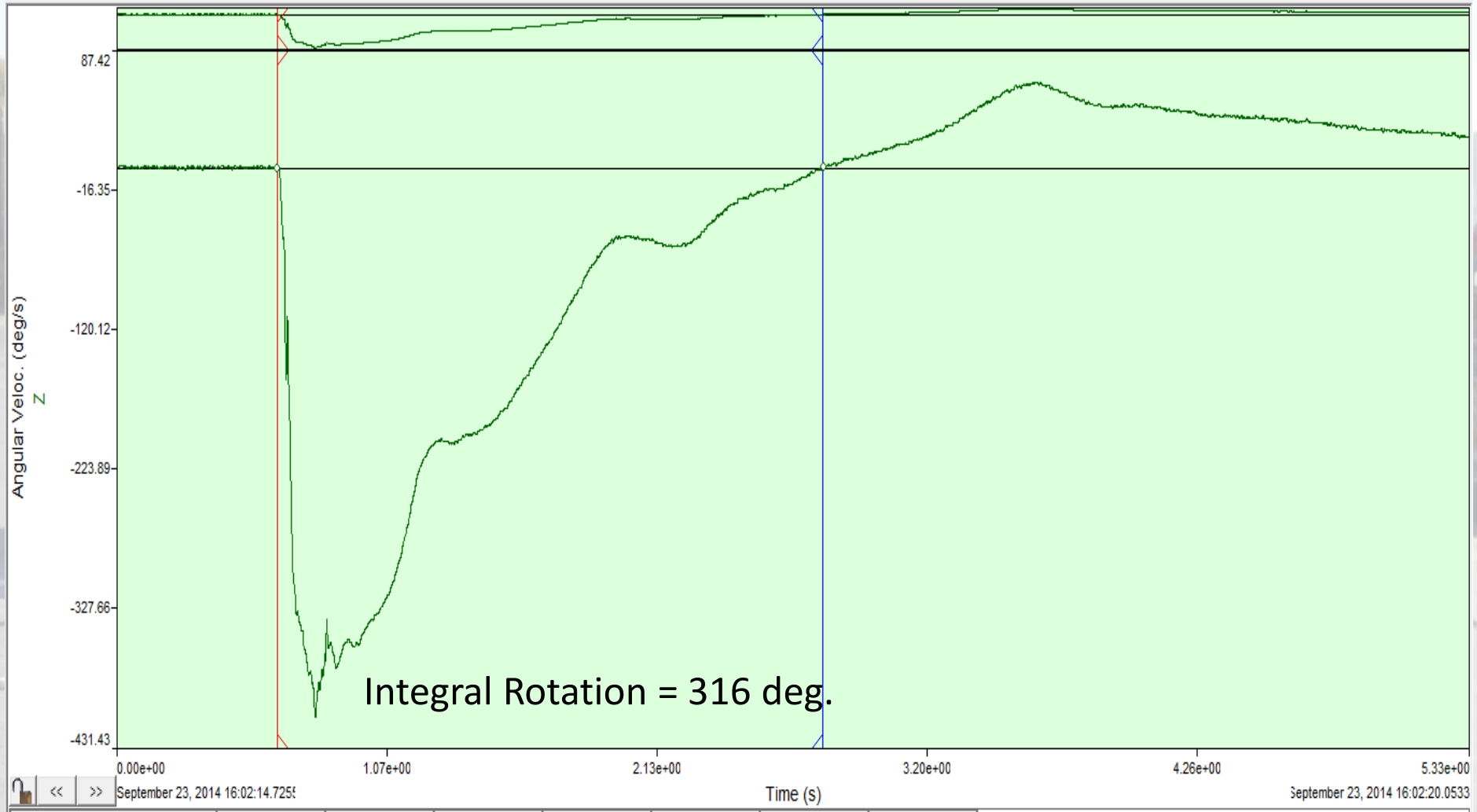
Event	Left Cursor Sample Number	Left Value g	Right Cursor Sample Number	Right Value g	Integral miles/hr	Delta Time s	Frequency Hz
f EDR3C #1951 1:1:X	688	-0.02147	917	0.02562	-2.492	0.07454	13.41
f EDR3C #1951 1:1:Y	688	0.02013	917	-0.08653	0.05819	0.07454	13.41

Crash # – Mustang CG 6DOF - A



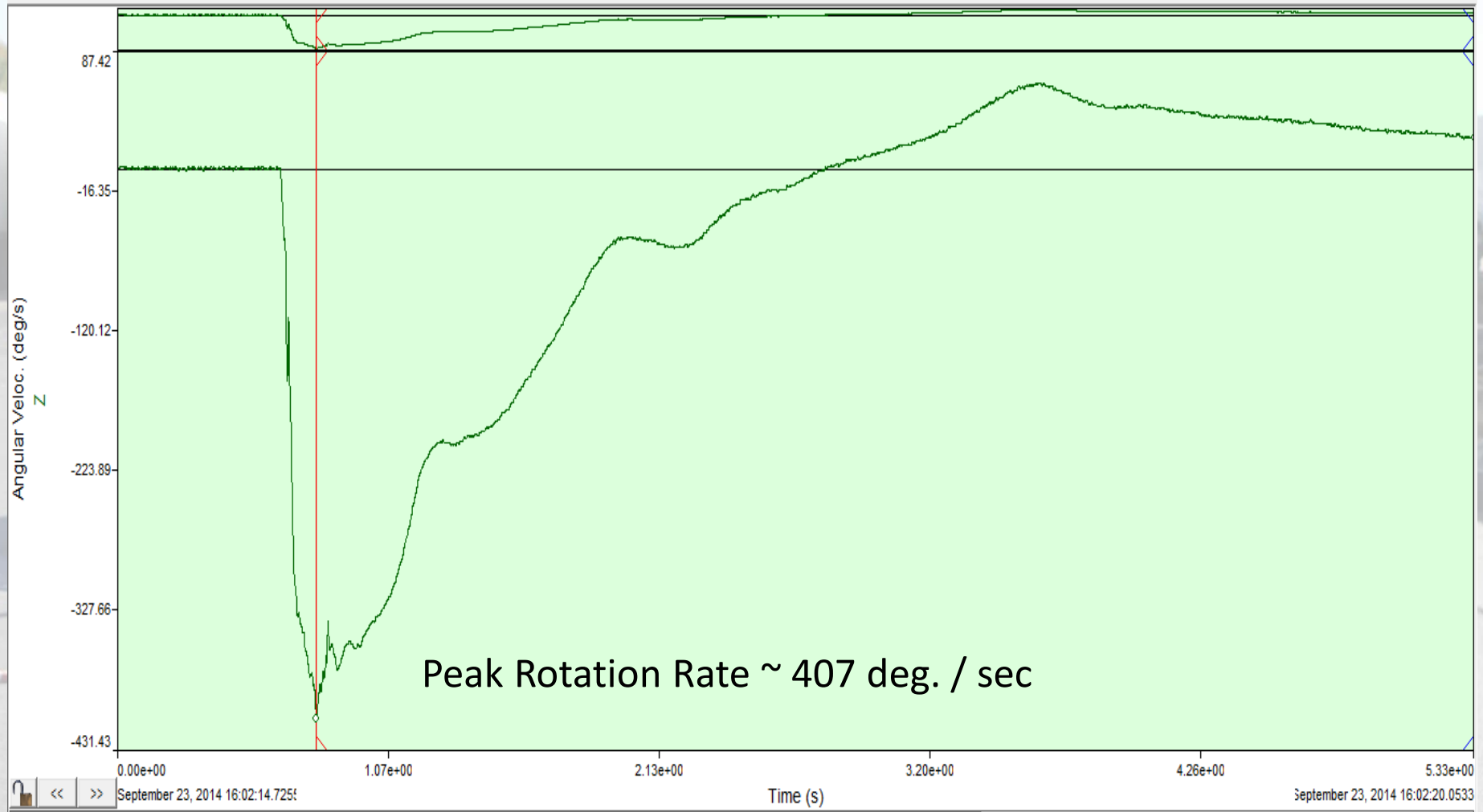
Event	Left Cursor Sample Number	Left Value g	Right Cursor Sample Number	Right Value g	Integral miles/hr	Delta Time s	Frequency Hz
f EDR3D #3045A 1:1:X	2031	0.07045	2268	2.039	2.701	0.07715	12.96
f EDR3D #3045A 1:1:Y	2031	-0.005397	2268	-0.5658	-16.41	0.07715	12.96

Crash # – Mustang CG 6DOF - B



Event	Left Cursor Sample Number	Left Value deg/s	Right Cursor Sample Number	Right Value deg/s	Integral deg	Delta Time s	Frequency Hz
f EDR3D #3045B 1:1:Z	1952	-0.5002	8549	1.026	-316.7	2.147	0.4657

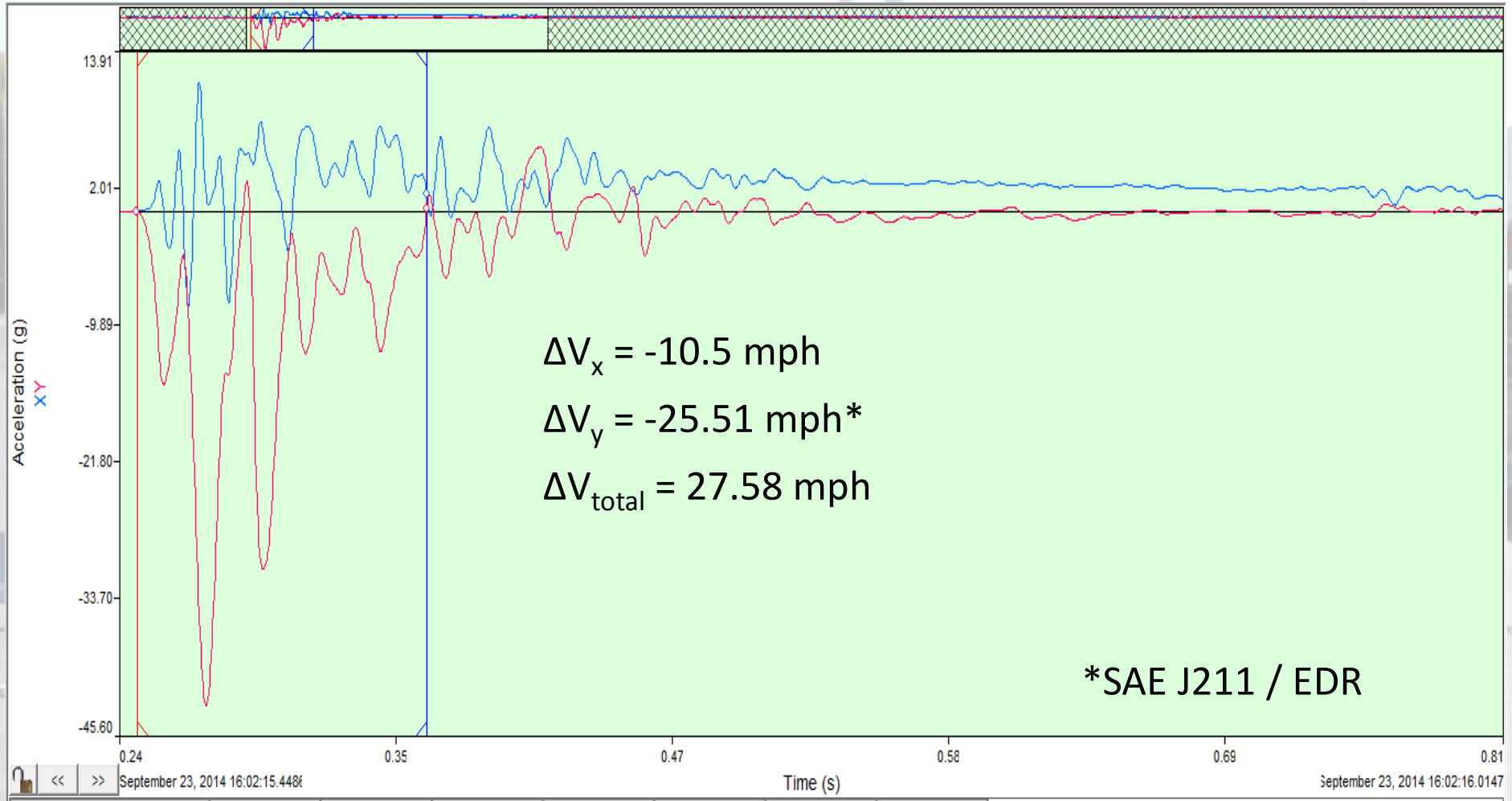
Crash # – Mustang CG 6DOF - B



Event	Left Cursor Sample Number	Left Value deg/s	Right Cursor Sample Number	Right Value deg/s	Integral deg	Delta Time s	Frequency Hz
f EDR3D #3045B 1:1:Z	2407	-407.7	16368	23.3	-189.4	4.545	0.22

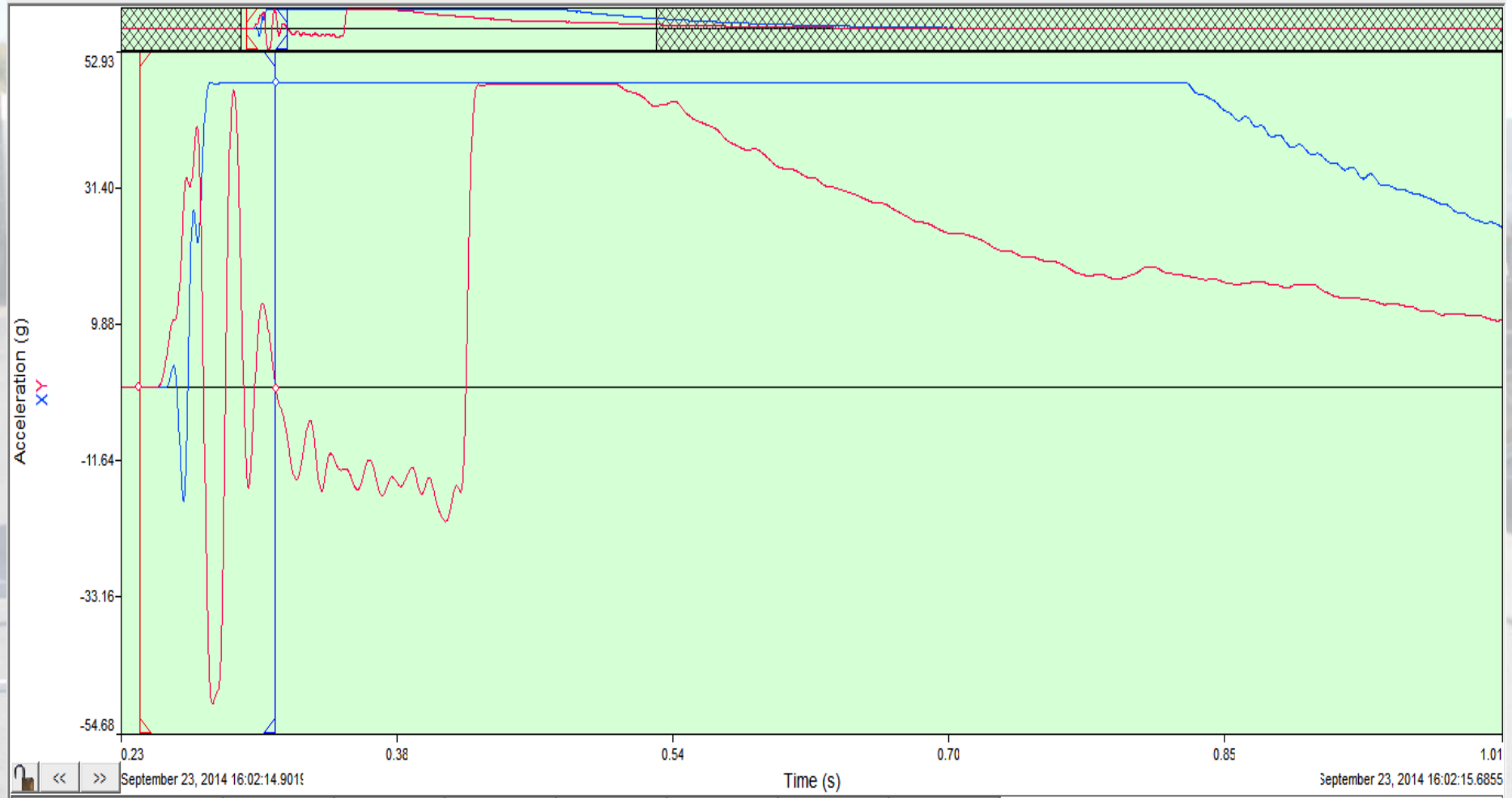
User Information

Test #3 – Middle IST



Event	Left Cursor Sample Number	Left Value g	Right Cursor Sample Number	Right Value g	Integral miles/hr	Delta Time s	Frequency Hz
f EDR3C #1751 1:1:X	757	0.01809	1122	1.448	7.329	0.1188	8.416
f EDR3C #1751 1:1:Y	757	-0.007089	1122	0.2683	-28.43	0.1188	8.416

Test #3 – Rear IST (On Bumper)



Event	Left Cursor Sample Number	Left Value g	Right Cursor Sample Number	Right Value g	Integral miles/hr	Delta Time s	Frequency Hz
f EDR3D #2211B 1:1:X	727	0.007327	965	47.96	46.43	0.07747	12.91
f EDR3D #2211B 1:1:Y	727	0.04689	965	-0.1591	8.356	0.07747	12.91

Total Delta-V Calculation

$$\Delta v_t = \sqrt{\Delta v_x^2 + \Delta v_y^2}$$

$$\Delta v_t = \sqrt{2.687^2 + 16.41^2} = 16.6 \text{ mi/h}$$

Delta-V for the Truck

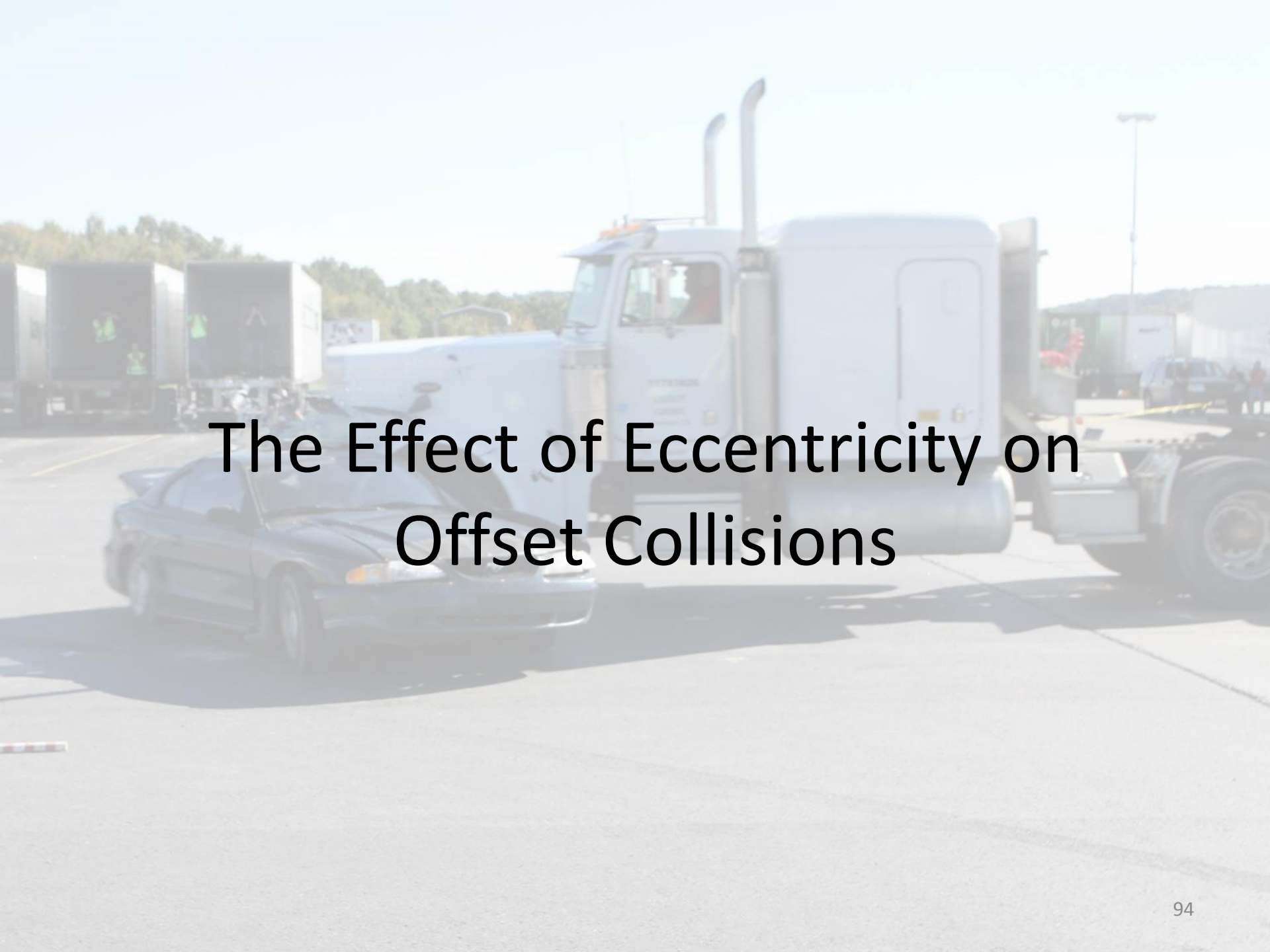
$$\Delta v_{truck} = \frac{\Delta v_{car} w_{car}}{w_{truck}} = \frac{(16.6)(3060)}{19000} = 2.7 \text{ mi/h}$$

Closing Speed (ignoring rotation)

$$v_c = \left(\frac{1}{1+e}\right)\left(\left|\Delta v_1\right| + \left|\Delta v_2\right|\right)$$

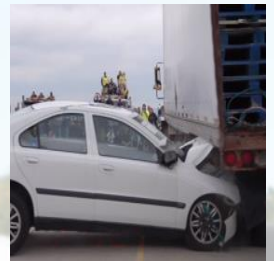
$$v_c = \left(\frac{1}{1+.1}\right)\left(16.6 + 2.7\right) = 17.5 \text{ mi/h}$$

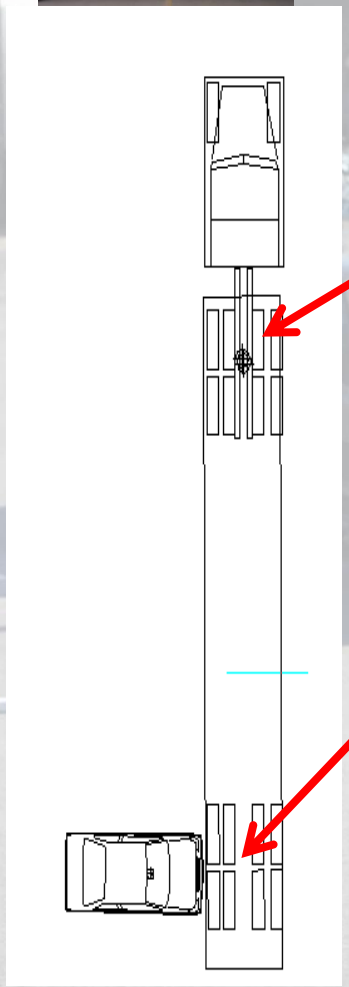
Measured Speed was 33 to 34 mi/h



The Effect of Eccentricity on Offset Collisions

Eccentric Crash Thought Experiment



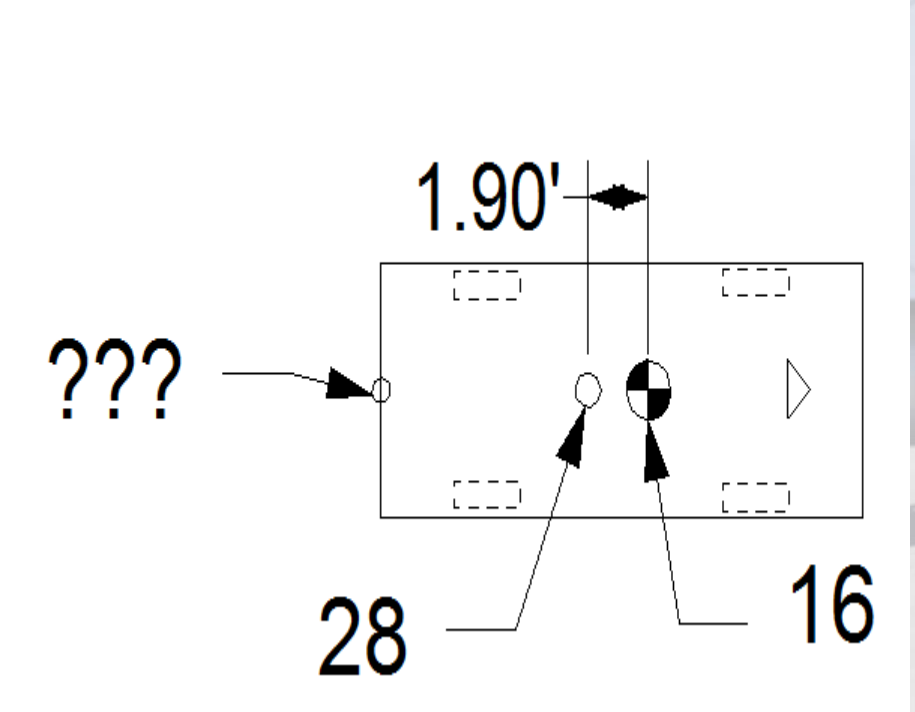


Q:What is the DeltaV Sensed by the trailer here at the kingpin?

A: 0 mph. An EDR here would miss 100% of the DeltaV

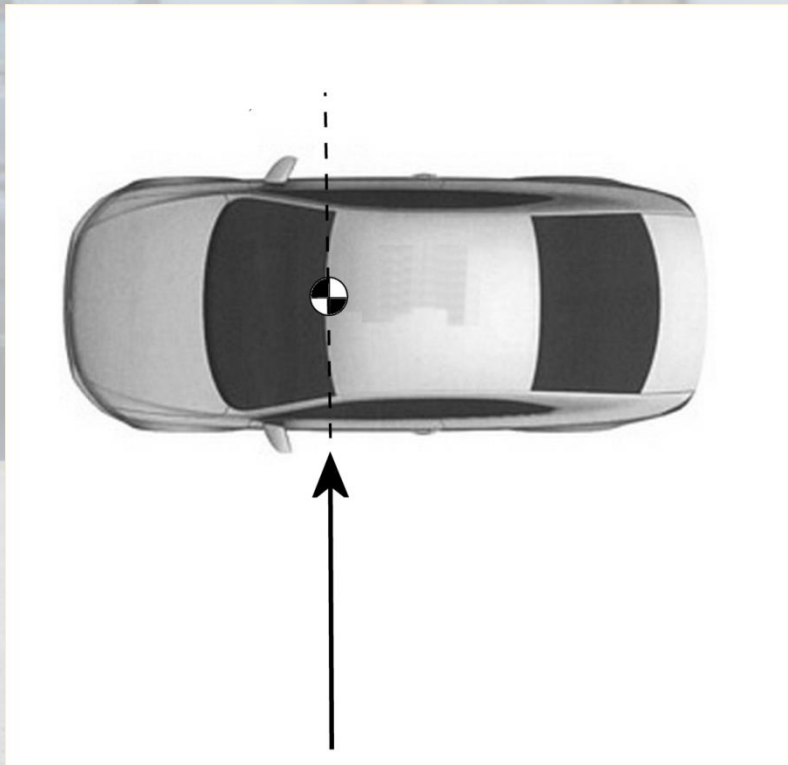
Q:What is the DeltaV Sensed by the trailer here at the crash center?

Delta-V from Mustang CT3



Increasing Eccentricity

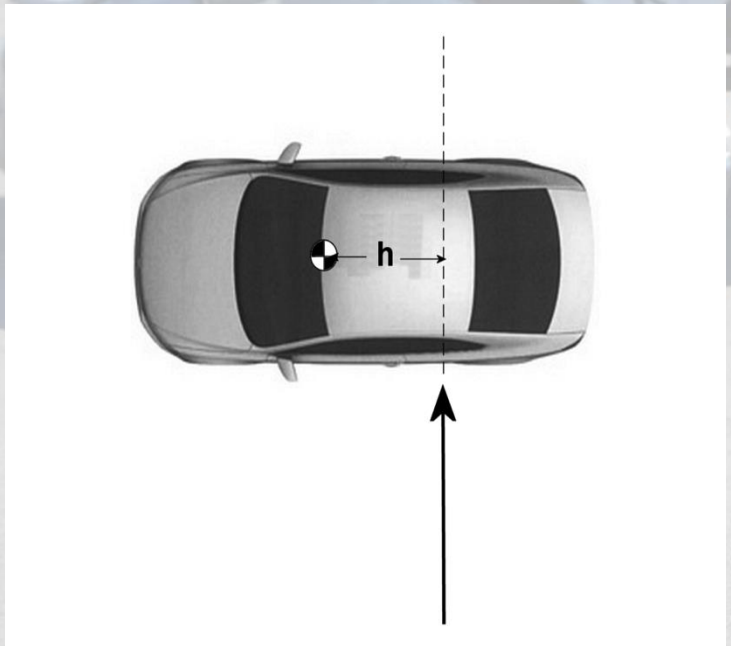
Central Collisions are easy. In central collisions the ACM DeltaV is the same as the vehicle DeltaV (when the module is at CG)

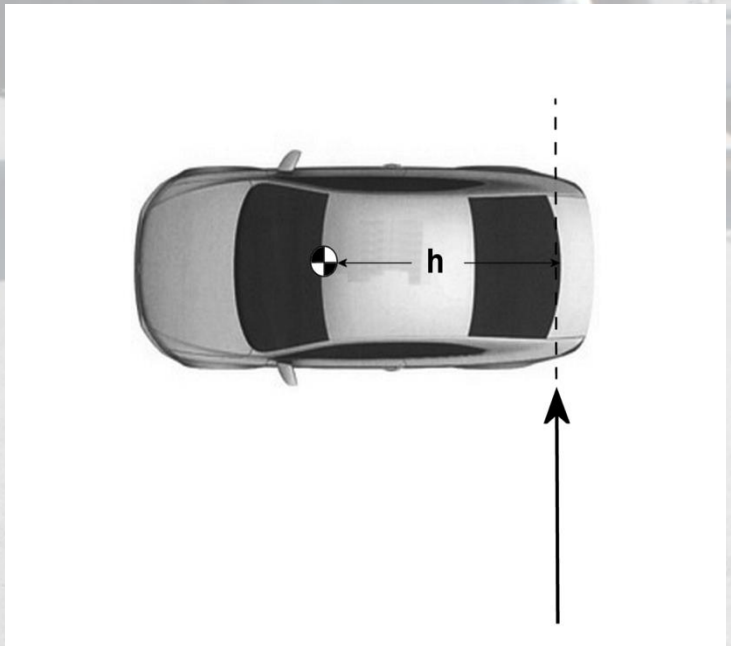


Increasing Eccentricity

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

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





Source of Effective Mass Ratio

- EMR is related to the length of the moment 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.

$$\gamma = \frac{k^2}{k^2 + h^2}$$

$$\text{Where} \quad k^2 = \frac{\text{Yaw Moment of Inertia}(g)}{\text{Vehicle Weight}} = \frac{I_y g}{W}$$

Determine Moment Arm

The Yaw Moment of Inertia

Look up in AutoStats

Calculate with regression equation (Garrott SAE 881767)

$$I_y = 1.03W - 1206 = (1.03)(3060) - 1206 = 1946 \text{ ft-lb-sec}^2$$

$$k^2 = \frac{I_y g}{W} = \frac{(1946)(32.2)}{3060} = 20.5 \text{ ft}^2$$

The Effective Mass Ratio

$$\gamma = \frac{k^2}{k^2 + h^2} = \frac{20.5}{20.5 + 4.8^2} = .47$$

Closing Speed

$$v_c = \left(\frac{1}{1+e}\right)\left(\frac{|\Delta v_1|}{\gamma_1} + \frac{|\Delta v_2|}{\gamma_2}\right)$$

$$v_c = \left(\frac{1}{1+.1}\right)\left(\frac{16.6}{.47} + \frac{2.7}{1}\right) = 34.6 \text{ mi/h}$$

Measured Speed was 33 to 34 mi/h

That's all Folks!
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