GM Technical Training

Frontal Air Bag Sensing

March 29, 2007

Agenda

- Sensing Overview
- History of Sensing Technology
- Sensing System Development
- Challenges with Discrimination
- Sensing Algorithms (Proprietary information - Slides removed)
- Sensor data vs. EDR
- Q&A

Sensing Overview

Overview

RESTRAINT SYSTEM COMPONENTS

- Structure
  - Bumper system
  - Front End Sheet Metal
  - Upper Rails and Mid Rails
- Restraints
  - Seat Belts and Pretensioners
  - Air Bags
  - Knee Bolsters
- Sensing System
  - SDM
  - Satellite Sensors
  - Wiring

The sensing system is part of a complex system designed to provide occupant restraint in vehicle collisions.

Sensing Performance Objectives

- Balance sensing performance to achieve occupant performance goals for moderate to severe impacts while reducing the potential for deployments in events where they are not needed.
- Determine deployment level vs. non-deployment level for pretensioner, Stage 1 and Stage 2.
- Determine when air bag should deploy for deployment level events.

Air Bag System Design Considerations

- Regulated Conditions (i.e. FMVSS208)
- Consumer Metric Tests (i.e. NCAP, IIHS)
- Other Field Relevant Impact Conditions (i.e. Bumper Underride and Pole Impact)
- Conditions Where Air Bags should not Deploy (Immunity Conditions)
- Evaluate Various Occupant Sizes

Evaluate Expected Usage

- Where Will Vehicle Be Driven?
    - Less Developed Road Systems
    - Off-Road Conditions
- How Will Vehicle Be Used?
    - Snow Plow Impacts

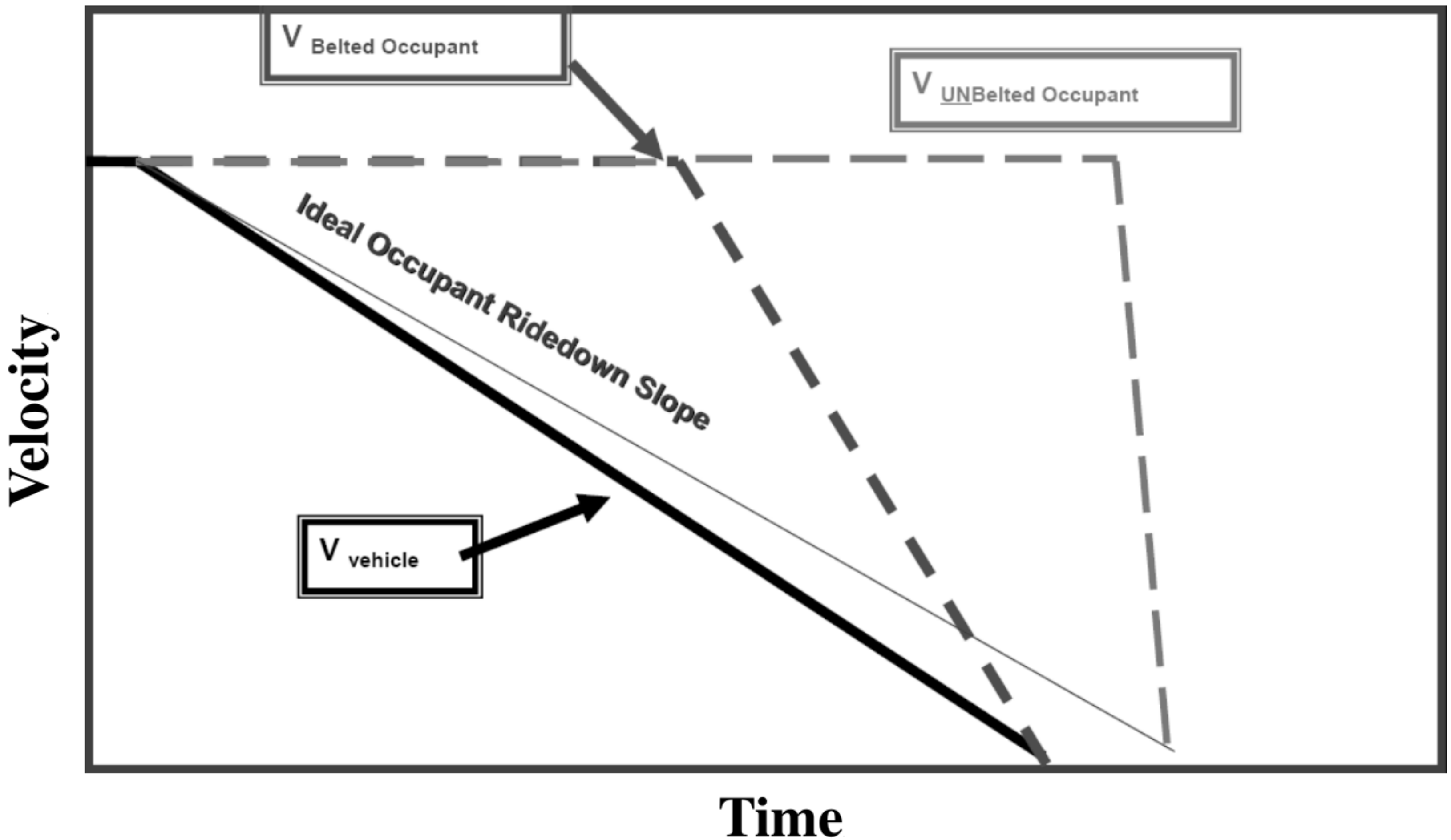
Considerations May Change

- Changes to Safety Regulations
- Additional Consumer Metric Tests
- Vehicle Usage Influences What Conditions May be Considered

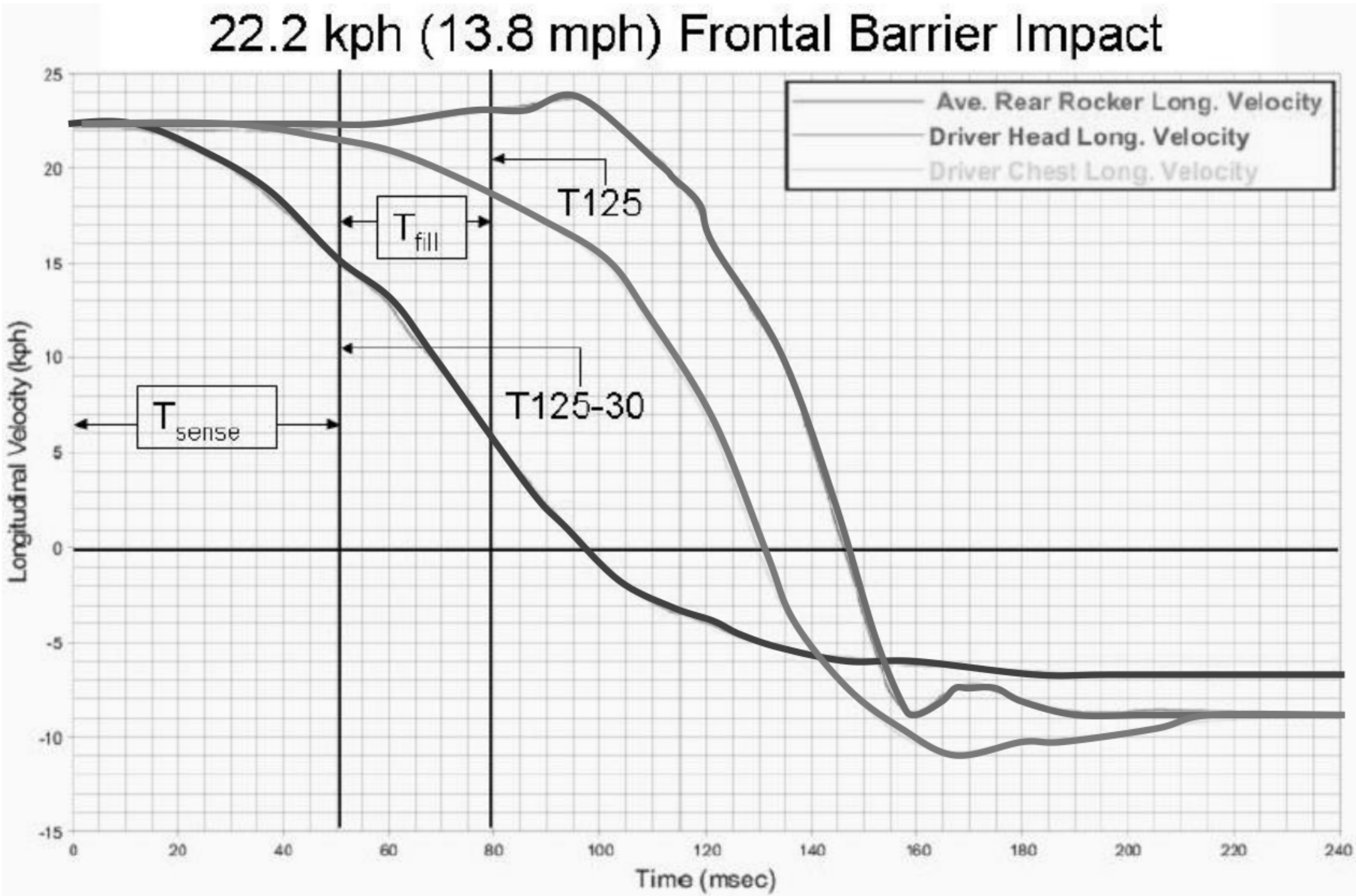
Frontal Air Bag Sensing

- Air Bag Sensors Measure Physical Parameters
- Identify Crashes Likely to Produce Injuries Above a Desired Level
- Air Bag Sensors Measure Vehicle Reaction to the Crashes
- Sensing System Deployment Decision is Based on Information From Vehicle Development Testing

Concept of "Ridedown"



Ridedown and Deploy Targets



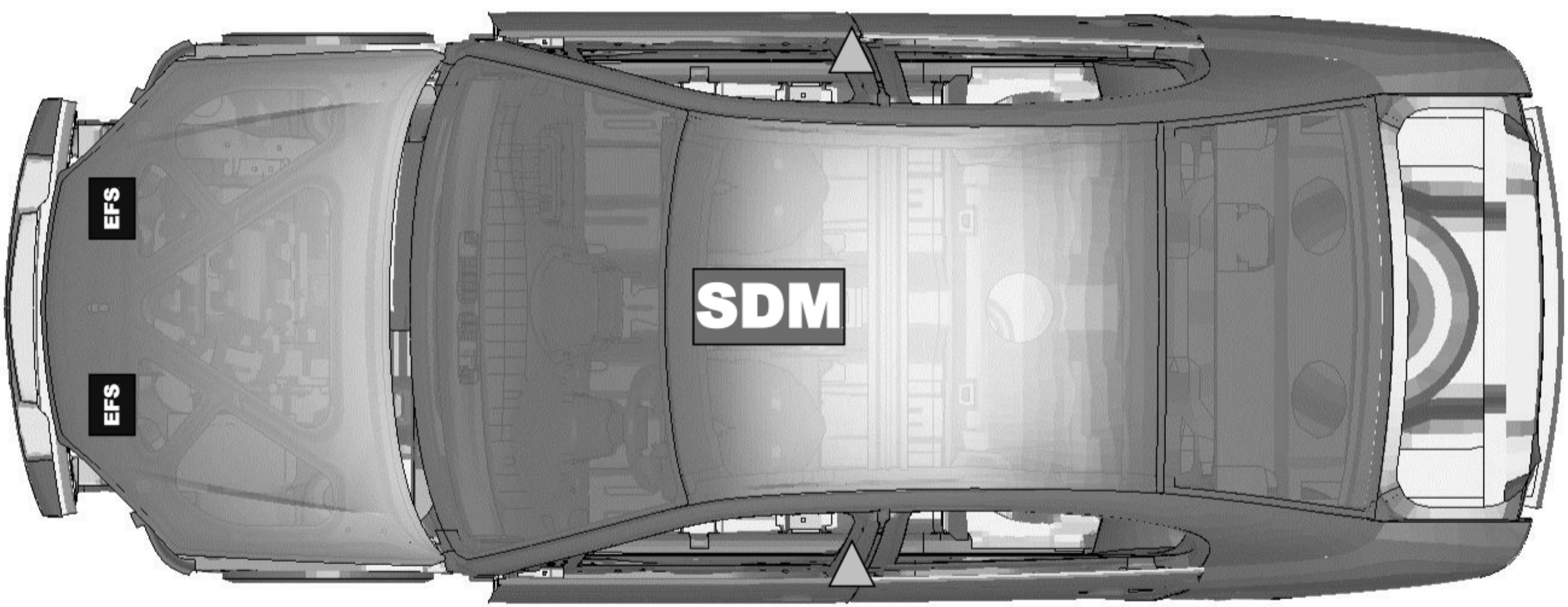
Crash Sensing Terms

- **Accelerometer**
  - Device used to quantify acceleration, velocity change or distance
  - A sensor which converts an acceleration from motion or gravity into an electrical signal
  - Acceleration integrated over time yields the change in velocity
  - Velocity integrated over time yields displacement or distance traveled

Crash Sensor Locations

EFS Electronic Front Sensor

SIS Side Impact Sensor



SDM Sensing and Diagnostics Module

Crash Sensing Terms

- **Crash Pulse**
  - Period when a vehicle is acting on an object or another vehicle and the resultant characteristics.
- **Acceleration**
  - The rate at which an object's velocity changes with respect to time.
- **Delta-V**
  - Change of Velocity
  - Velocity is a vector quantity with both magnitude and direction
  - Delta-V in a crash is the difference between the vehicle's impact velocity and the post impact velocity
  - Delta-V is the area under the curve in a plot of acceleration and time.

Crash Sensing Terms

GM

- Safing/Arming
  - A redundant method to confirm that an event is occurring
- Deployment Time
  - The time at which the vehicle's restraint countermeasures are deployed. Deploy time estimates of "T125-30" (the time it takes an unrestrained occupant to move 5 inches minus time it takes to inflate the bag) or targets based on occupant simulation are used prior to having barrier test data.
- Algorithm Enable
  - The algorithm is the procedure (program) used to reach the decision of whether and when to deploy restraints
  - When acceleration exceeds a predetermined value, the SDM begins the sensing algorithm calculations to determine whether to deploy the air bags. Typically the enable has been based on acceleration at the SDM, but in some systems the signal at the EFS may enable the algorithm.

History of Sensing Technology

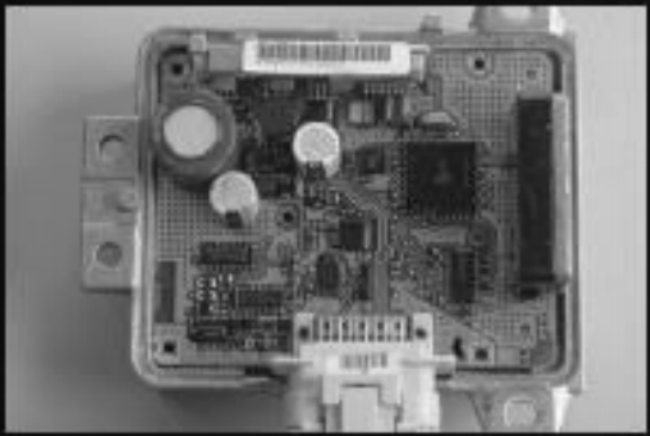
Air Bag Sensing History

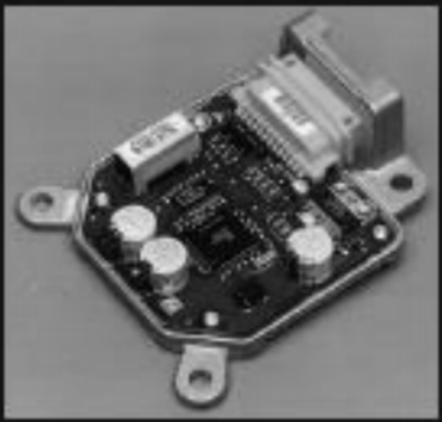
- Electro-mechanical sensors with a Diagnostics and Energy Reserve Module (DERM)
- First Generation SDM’s
  – Single-Point Accelerometer based
- Second Generation SDM’s
  – Newer technology hardware
  – Increased Software Capability
  – More Sophisticated Sensing Algorithms
- Electronic Front Sensors
  – Contain accelerometer and microprocessor
  – Process acceleration, make decision and transmit to SDM
- Raw Data Sensors
  – All computations and decisions made at SDM

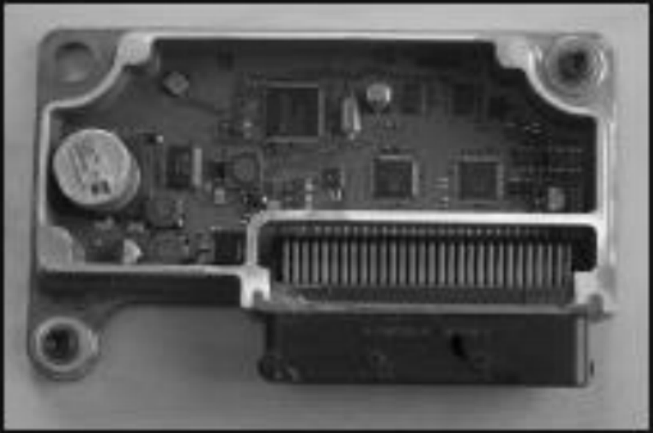
Today's Sensing and Diagnostics Module (SDM)

- Located in Passenger Compartment
- Contains:
  - Accelerometer
  - Microprocessor
    - Diagnostics
    - Deployment Control Algorithm
  - Method for Safing
  - Devices that Turn on Current for Deployment Loops
- Communicates on Vehicle Data Network
  - Diagnostic messages
  - OnStar Notification
  - Event Data Recording

SDM Technology







Sensing System Development

Predictive Sensing

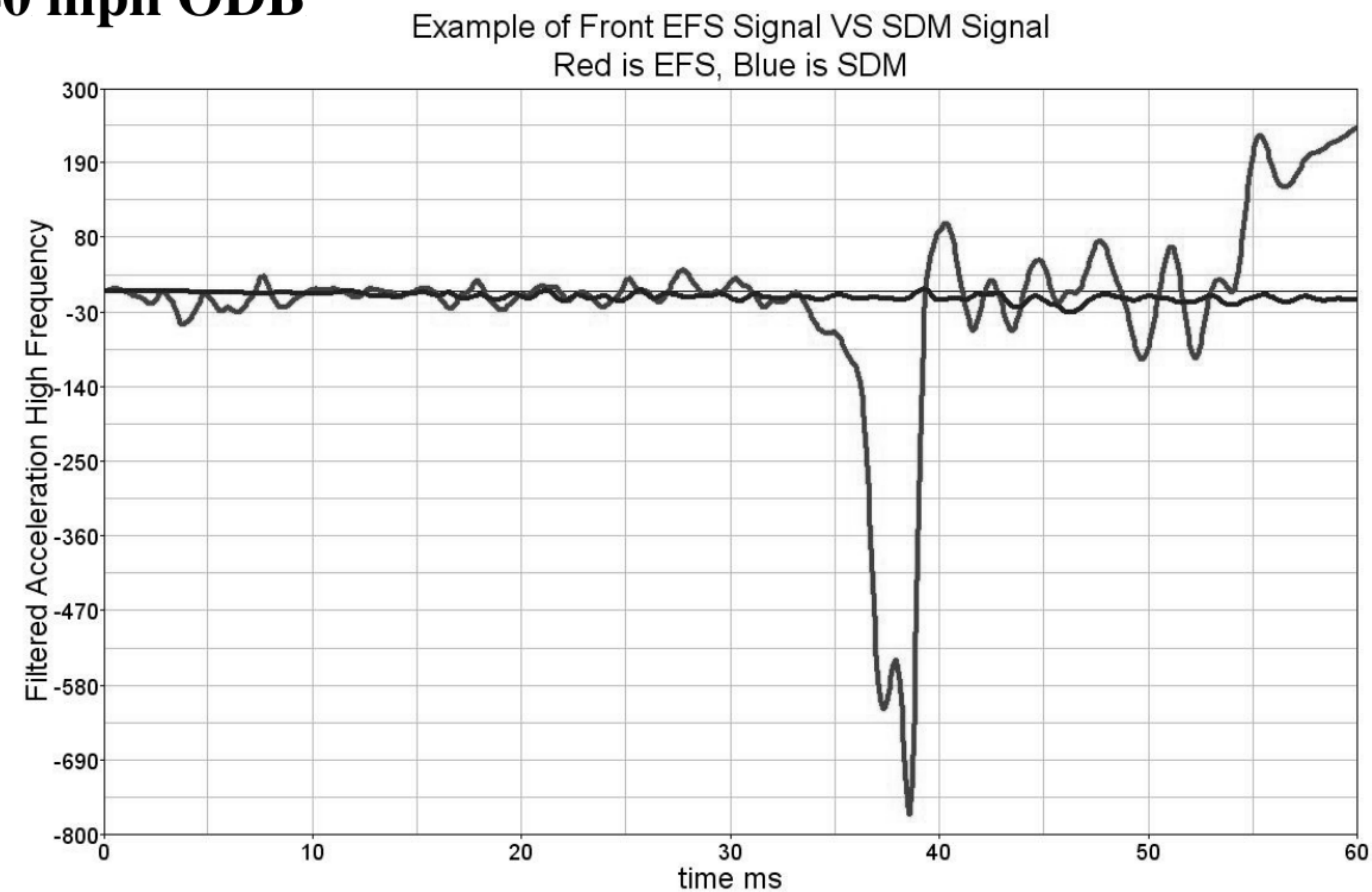
- **Crash Sensing Must Be Predictive**
  - The sensing system must anticipate collision severity that warrants deployment of the occupant restraints.
  - Sensors respond to the input at their location, regardless of the actual point or angle of impact.
  - When the algorithm is enabled, the SDM calculates if the crash parameters are of sufficient severity to deploy the occupant restraints.
  - Deploy decisions are not based on total Delta-V, but on terms that evaluate the early portion of crash pulse … usually in the first 10 to 60 msec of the crash.

Sensing Development Process

- Develop Air Bag System Test Plan
- Acquire test data for sensing development
- Evaluate occupant data to determine deployment thresholds and target deploy times
- Work with sensing system supplier to determine sensor locations and develop specific sensing performance
- Conduct additional testing as needed
- Review final sensing performance
  - Balance between timely deployments and immunity levels
  - Decisions may be based on vehicle data, simulation results or engineering judgment

Location in Vehicle vs. Pulse

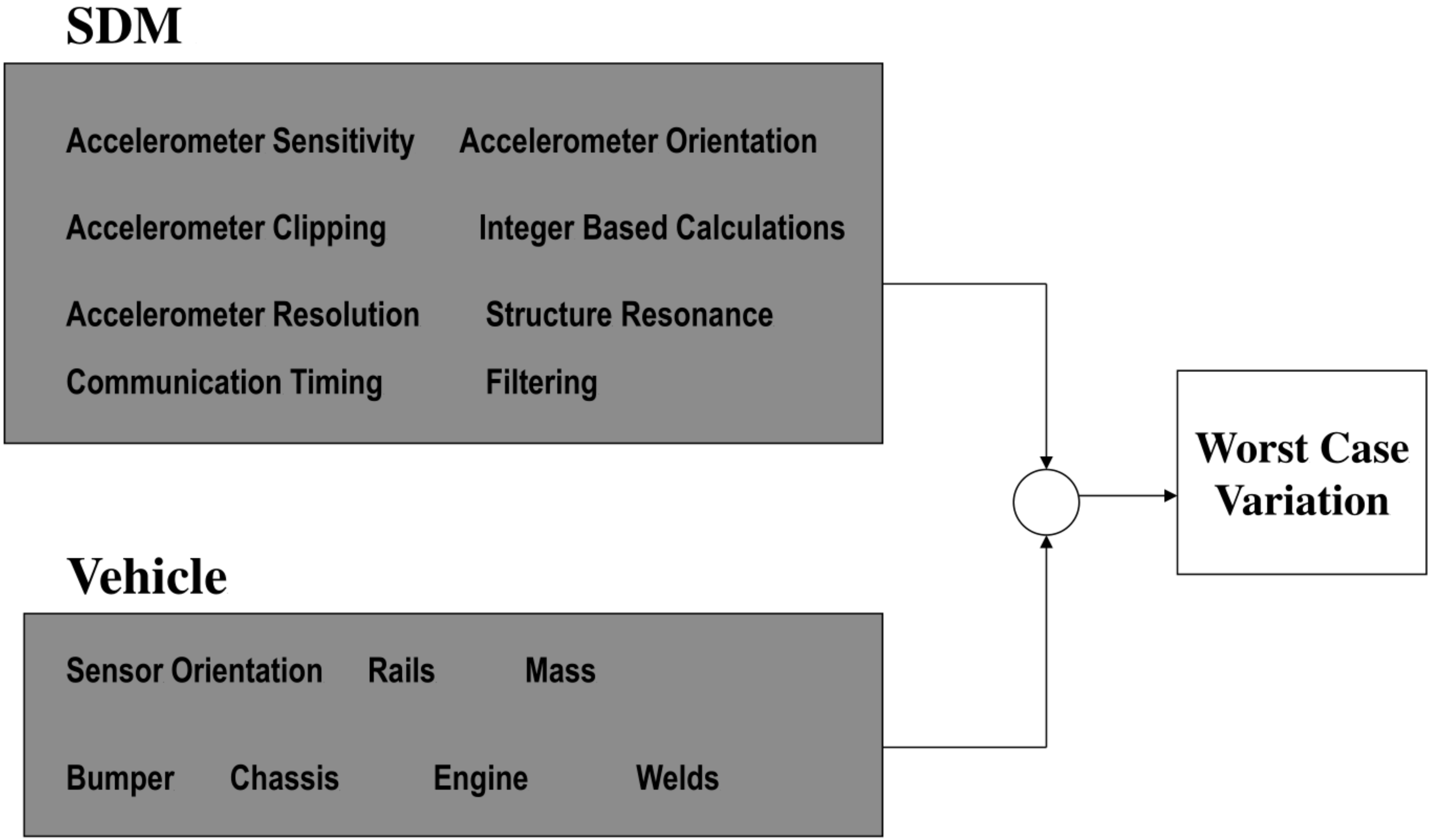
40 mph ODB



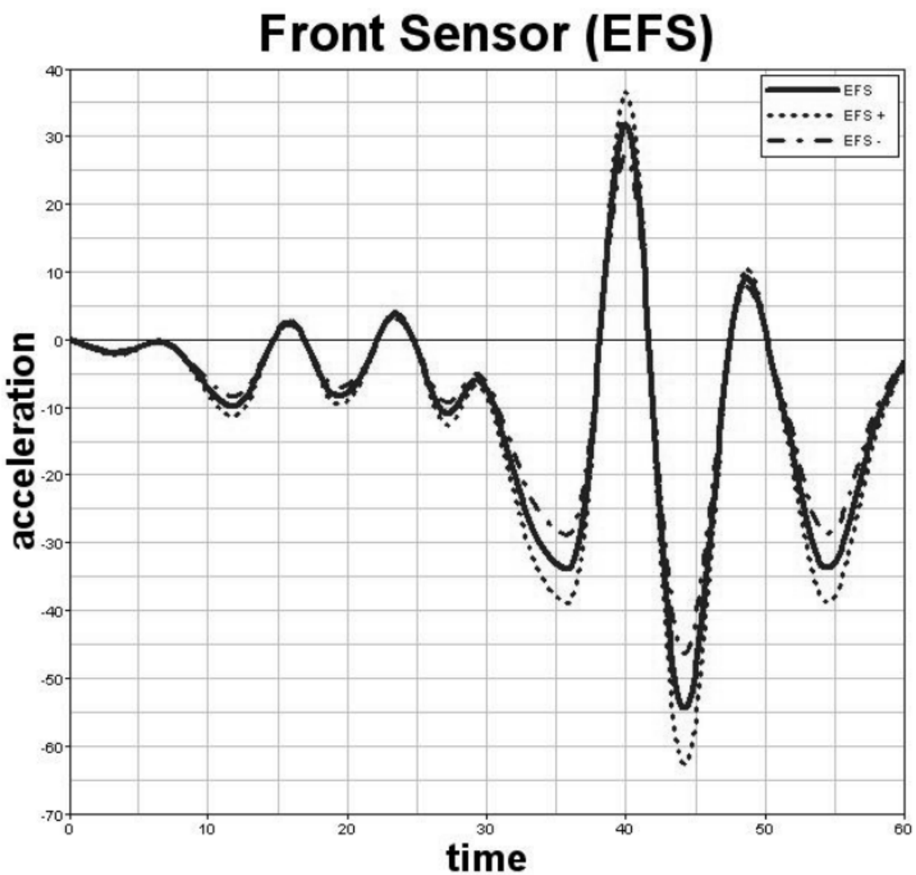
Number of Sensors

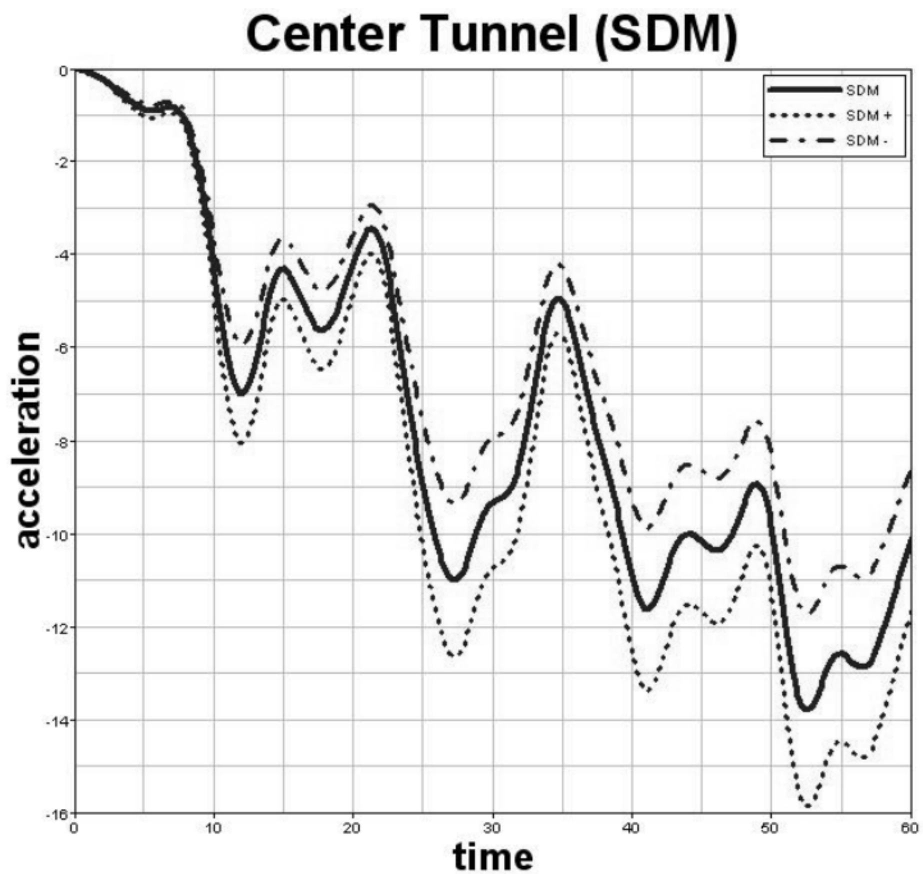
- Factors in Determining Front Sensor Quantities Include:
  - Safety Regulations and Consumer Metric Tests
  - Sensing Algorithm
  - Vehicle Usage
  - Immunity Conditions and Goals
  - Crash Pulse for Deployment Events
  - Test Data For Immunity Events
  - Target Time for Air Bag Deployments
  - Available Sensing Technology

Contributions to Sensing Variability



Assessing Sensing Variability





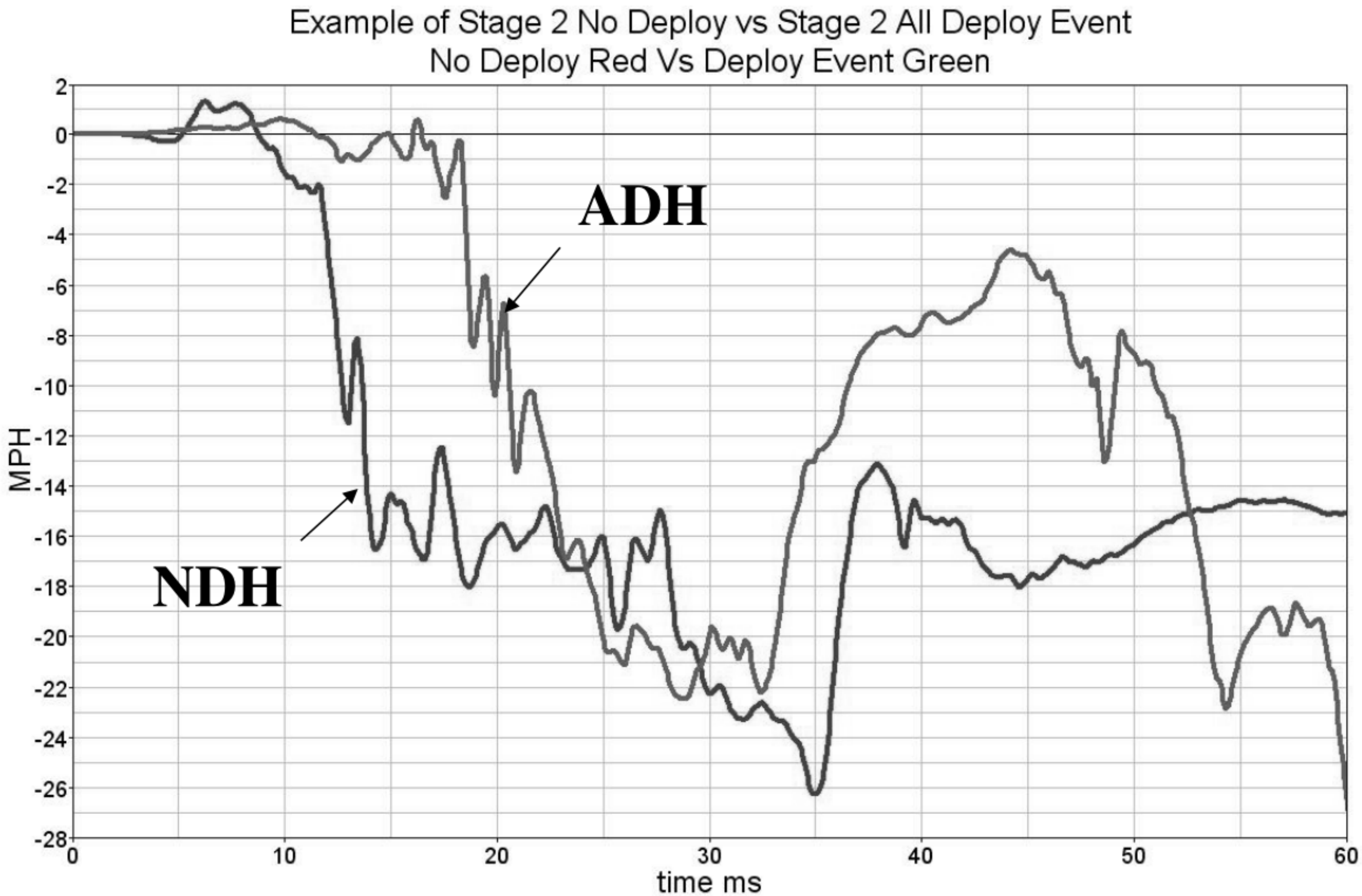
Challenges with Discrimination

How to Make Timely Decisions

- Create measures that allow separation of events without respect to the event type. (e.g. non-deploy barrier from a 25 mph ODB)
- Create measures that allow separation of events of increasing severity with a particular crash type, and develop measures that can classify the crash as a pole, full frontal, angle, ODB, etc.
  - Once event is classified, the signals are processed by the algorithm with calibration values or thresholds related to that event type.
- Use information from additional vehicle locations.

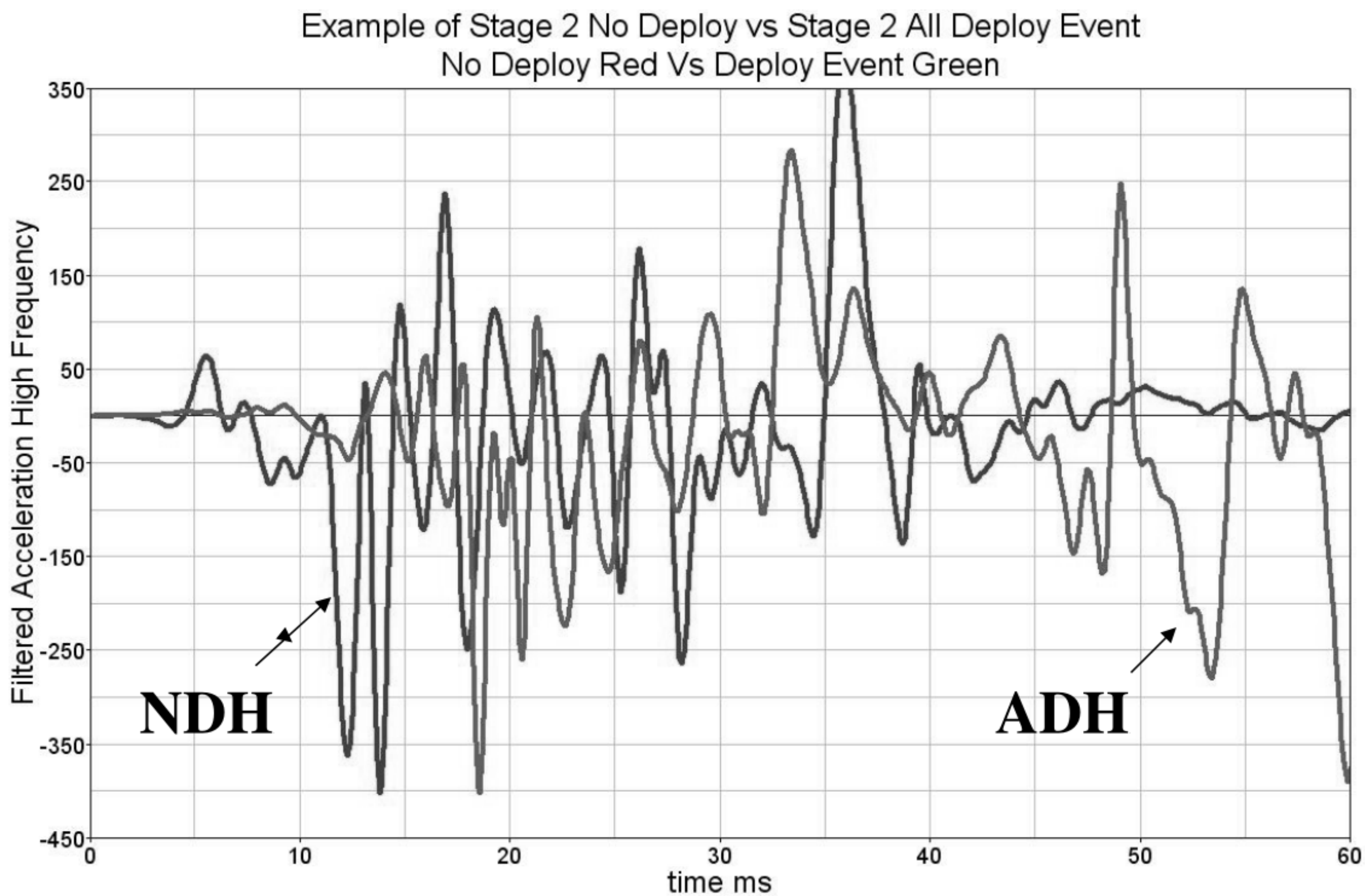
Discrimination Challenges

16 mph Frontal (NDH) vs. 40 mph ODB (ADH) - Velocity



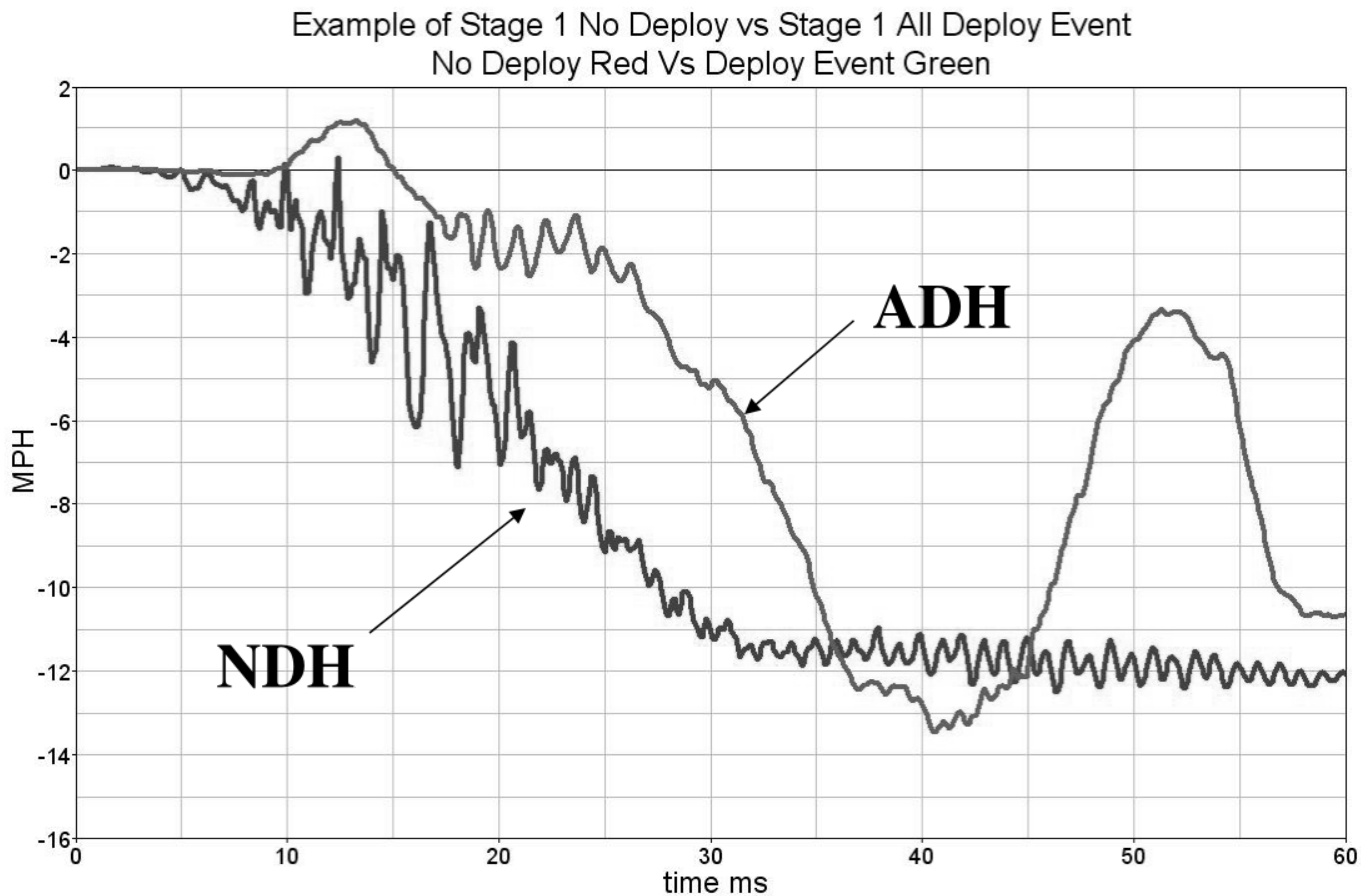
Discrimination Challenges

16 mph Frontal (NDH) vs. 40 mph ODB (ADH) – Acceleration



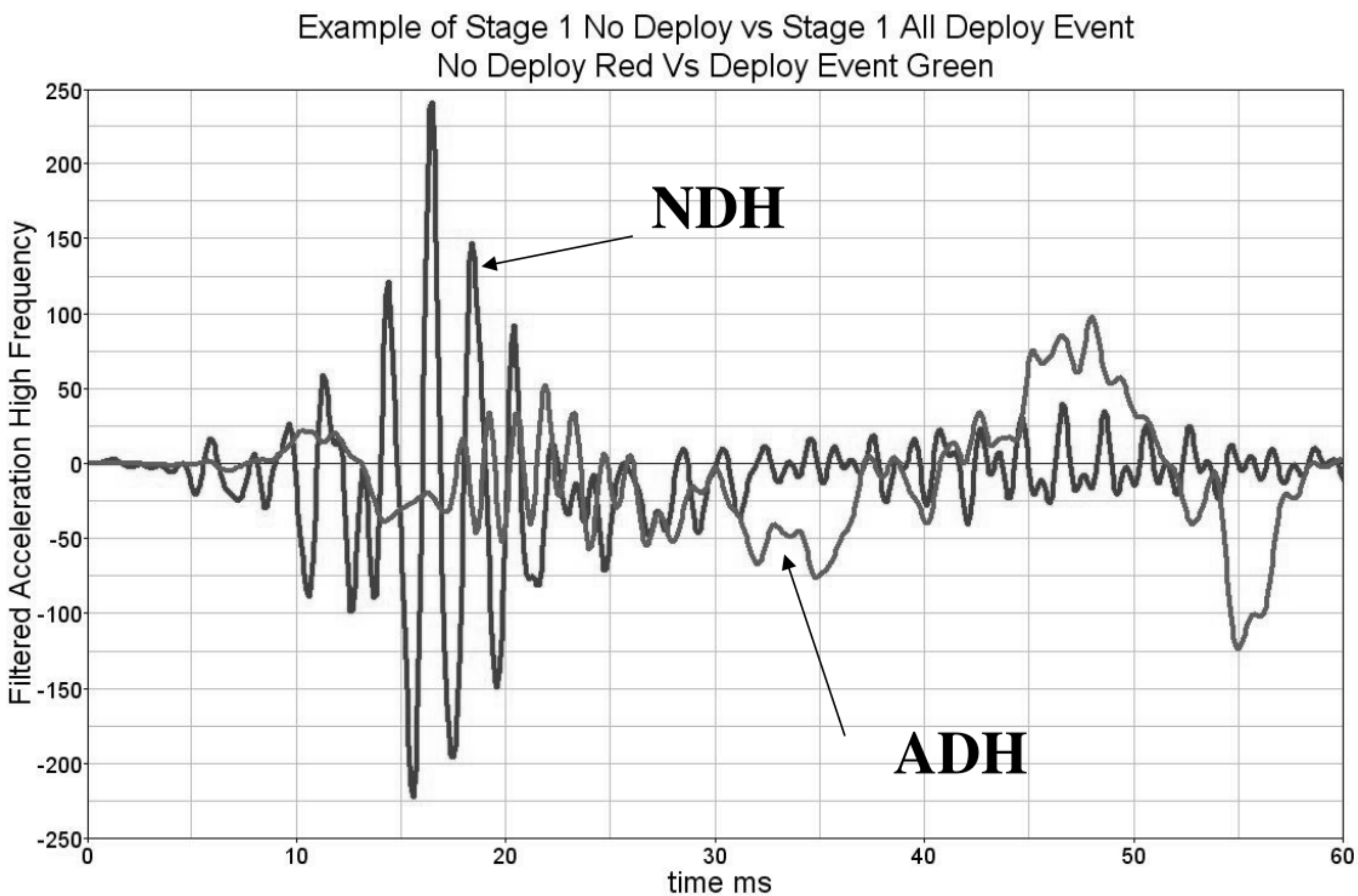
Discrimination Challenges

Frontal (NDL) vs. 20 mph Angle (ADH) - Velocity



Discrimination Challenges

Frontal (NDL) vs. 20 mph Angle (ADH) – Acceleration



Parameters Used in Sensing

- Delta-V (at SDM or EFS location)
- Average Acceleration (at SDM or EFS location)
- Slope of Acceleration (at SDM or EFS location)
- Oscillation of Acceleration (at SDM or EFS location)
- Ratio of longitudinal to lateral delta-v
- Ratio of longitudinal to lateral slope of acceleration
- Difference between signals at EFS and SDM
- Difference in signals between EFS (two EFS system)
- Crash classification as a function of time

- The parameters used vary between different sensing algorithms and different sensing suppliers.

Sensor data vs. EDR

When Should An Airbag Deploy?

- Sensing system is developed using data collected during vehicle development
- During an event sensors react to the inputs experienced at their location
- The sensors make a decision by comparing the inputs from the event being analyzed with thresholds that were determined by the data from the tests used to develop the air bag system
- The sensors deploy the air bags if they predict that the event will be severe enough for an air bag

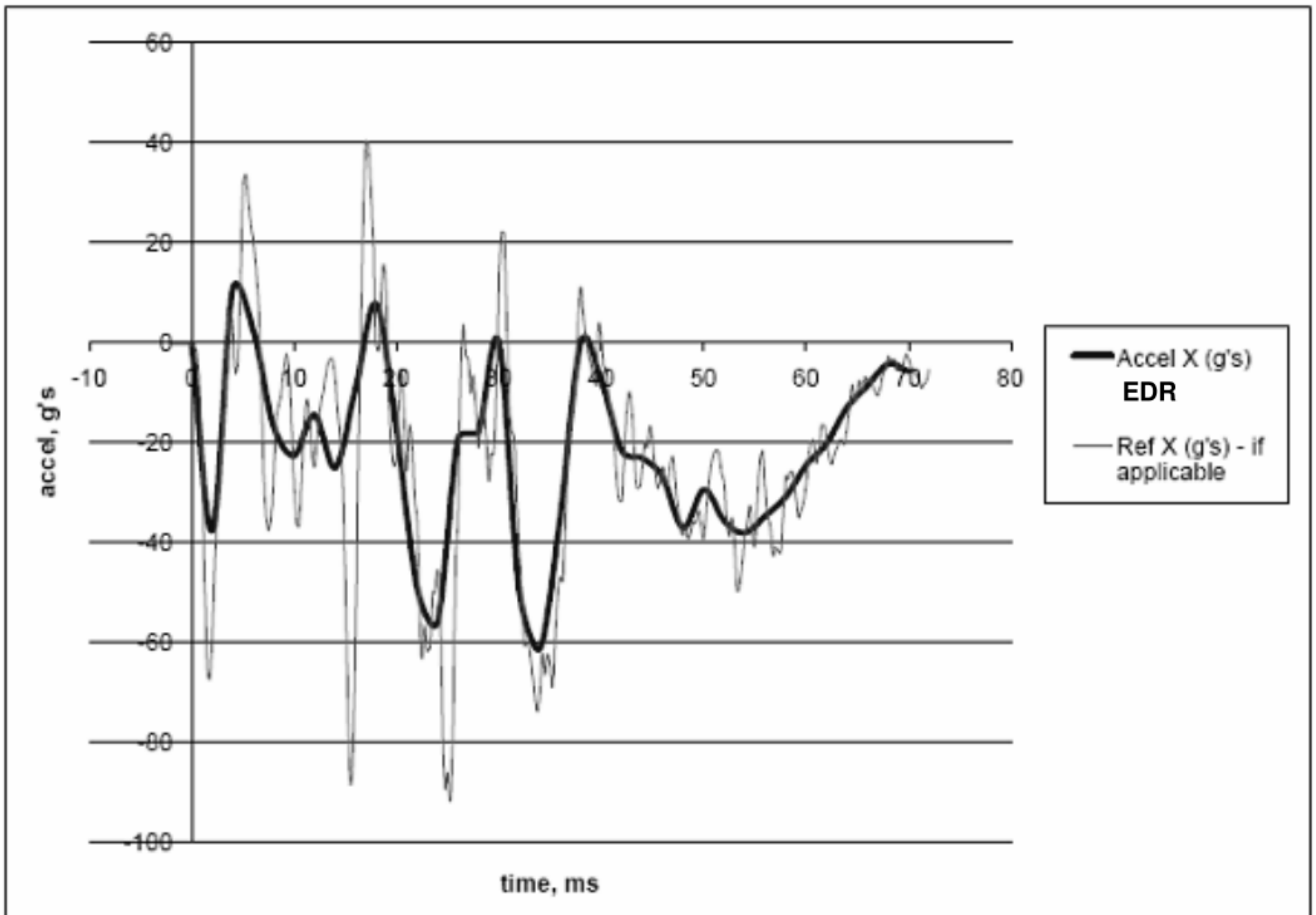
Sensing Decision is Not Determined By:

- Vehicle Speed Prior to the Collision
  - Speed can influence crash severity
- Delta-V of the Crash
  - Crash severity is also influenced by the time to reach the Delta-v
- Barrier Equivalent Velocity of the Crash

A Comment on Event Data Recorder (EDR)

- The top priority of the SDM is to make deployment decisions and perform diagnostics on the restraint system
- The data stored in EDR is a subset of the information that is available to the SDM to make deployment decisions
- EDR records every ten msec, whereas sensors sample at 1 to 4 samples per msec.

Accelerometer Signal vs. EDR at SDM



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Cc: Smith, Daniel <NHTSA>[Daniel.Smith@dot.gov]
To: Cooper, Thomas <NHTSA>[Thomas.Cooper@dot.gov]
From: Cooper, Thomas <NHTSA>
Sent on behalf of: Cooper, Thomas <NHTSA>
Sent: Thur 3/1/2007 4:15:11 PM
Importance: Low
Sensitivity: None
Subject: GM Quarterly Meeting
Categories: 0x00000003

When: Thursday, March 29, 2007 1:00 PM-4:30 PM (GMT-05:00) Eastern Time (US & Canada).
Where: ODI Conference Room

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GM Quarterly Meeting in the afternoon.

GM technical training session in RM 2301 in the morning. (I will send out an invite on this portion soon.)

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NHTSA/GM Quarterly Review

March 29, 2007

Washington, DC

AGENDA

Time	Subject	Presenters
	March 29, 2007	
9:00	➢ Principles of Vehicle Operation Air Bag Sensing .... Break.. *10 mins* Air Bag Field Assessment Techniques	Matt Jerinksy *(WebEx)* Brian Everest *(WebEx)*
11:30	➢ Lunch	All
1:00	➢ Review of Open Investigations .... *90 mins*	Keith Schultz *(WebEx)*
	➢ GM Investigation Metrics	
2:30	▪ Internal Investigation Metrics .... *5 mins*	Doug Wachtel *(WebEx)*
2:35	▪ TREAD Metrics .... *5 mins*	Gay Kent *(WebEx)*
2:40	➢ External Investigation Metrics & Recall Completion Rates .... *15 mins*	Keith Schultz *(WebEx)*
2:55	➢ Roundtable.. *20 mins*	All *(WebEx)*
3:15	➢ Seat Belts Workshop .... *45 mins*	Brian Stouffer *(WebEx)*
4:00	Adjourn	

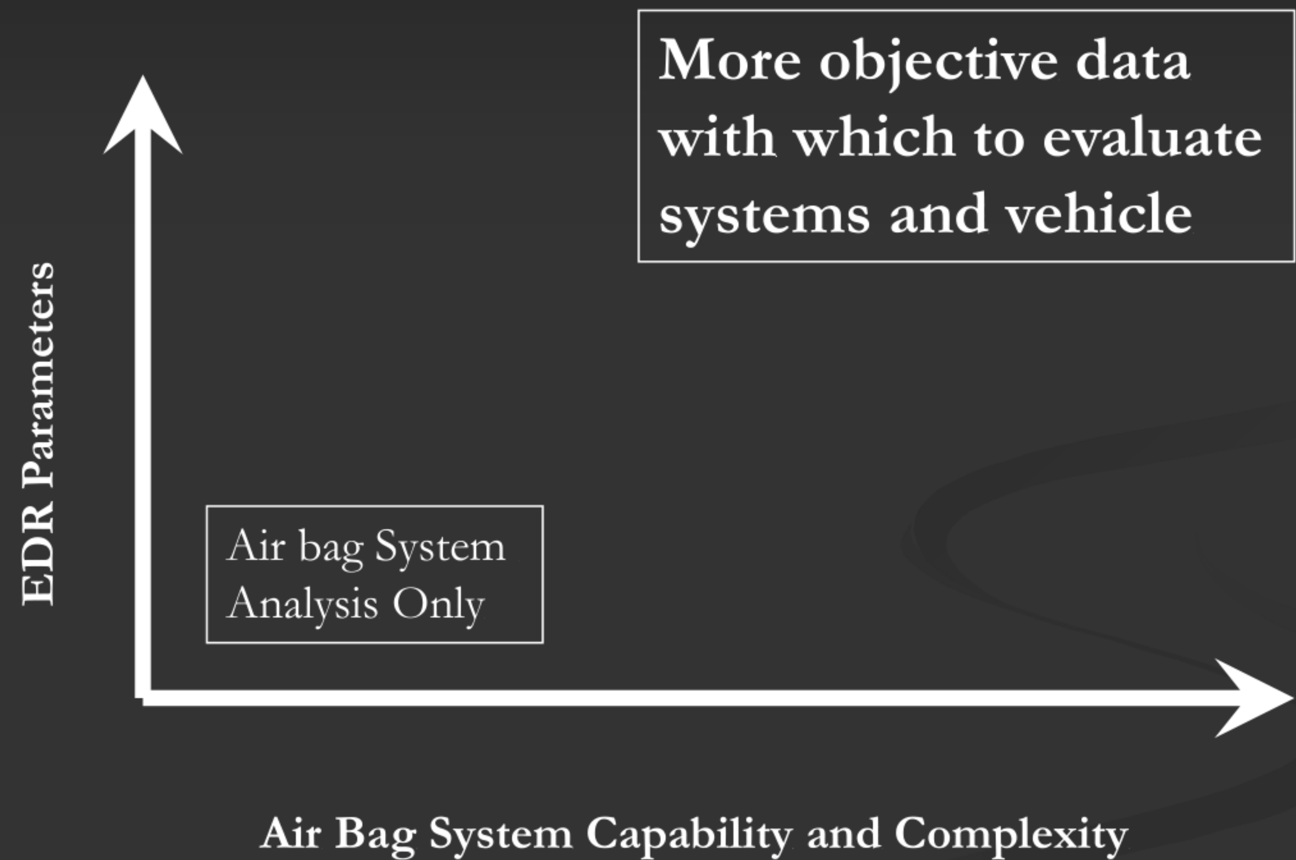
Field Events and Event Data

- **Event Data Recorder (EDR): Historical Perspective**
- **Analysis Overview**
- **Examples from the Field**
  - Example One: Concatenated crash
    - Proper air bag deployment?
    - Commanded roof rail air bags?
  - Example Two: New rollover technology
    - Proper system operation?

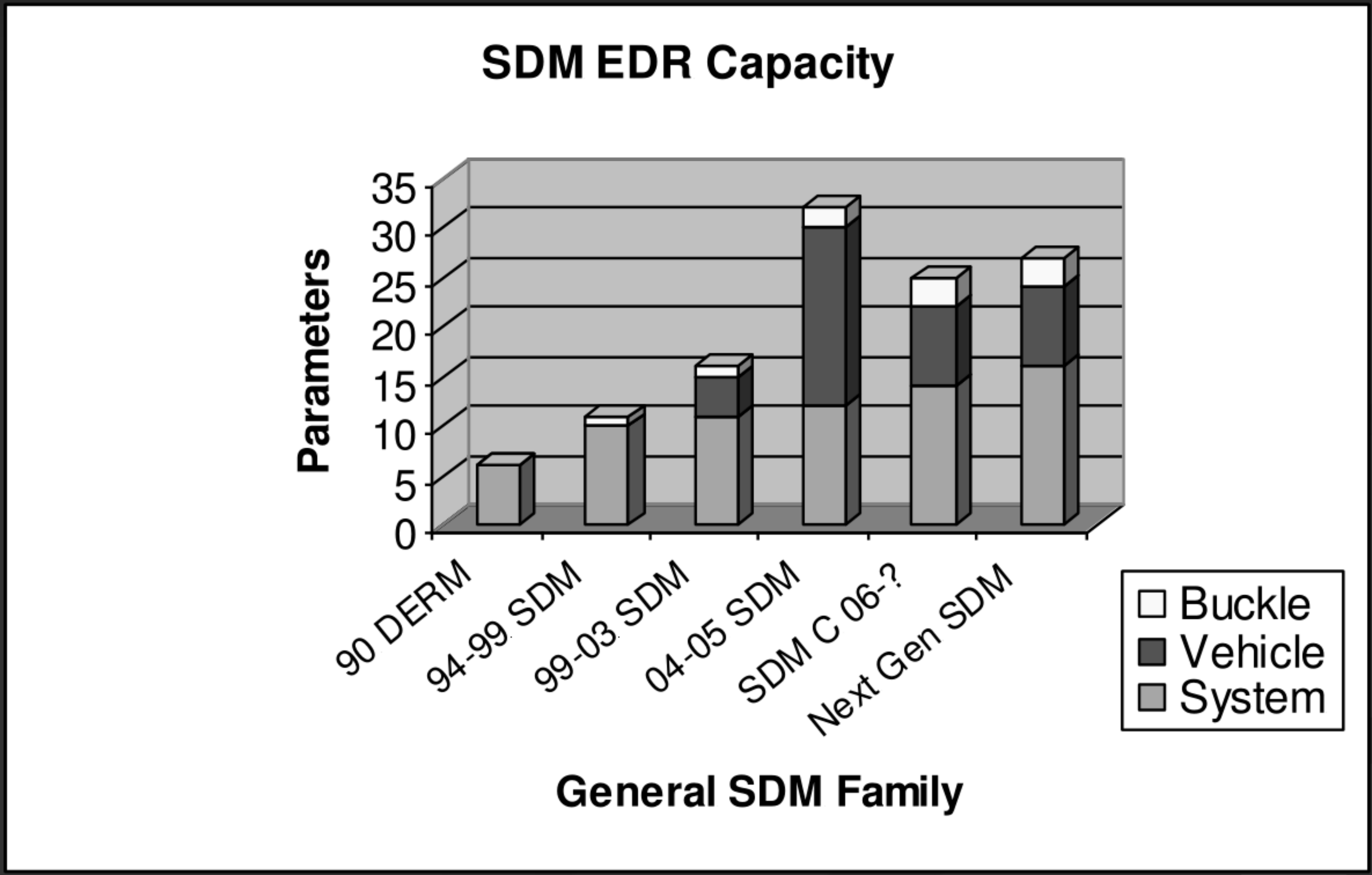
Event Data Recording (EDR)

- Sensing and Diagnostic Module (SDM) Function
- The SDM is not a "Black Box" recorder
- The SDM's top priorities
  - Detect Crashes
  - Deploy the airbags if necessary
  - Perform system diagnostics
- EDR data has evolved over time

EDR Evolution



Simplified History of EDR Capacity Air Bag Controllers 1990-2012



DERM – Diagnostic Energy Reserve Module

SDM – Sensing and Diagnostic Module

EDR – Event Data Recorder

First & Second Generation SDM
(1994 MY Introduction)

- Records Deployment and Non-Deployment Events
  - DERM – Deployment Only
- Includes information at time of event:
  - State of Air Bag System Warning Lamp
  - Warning Lamp "On Time"
  - Air Bag System Fault Codes
  - Ignition Cycles
  - Longitudinal Delta-V vs. Time (max velocity approximately 28 mph)
  - Time from algorithm enable to deployment command
  - Thresholds Exceeded
  - Max Delta-V for Non-Deployment Event
  - Driver's Seat Belt Switch Status
- Next Generation SDM (1996 MY introduction)
  - Max delta velocity of approximately 56 mph
  - PSIR switch suppression status
  - Diagnostics for side impact air bags

Third Generation SDM
(1999 MY INTRODUCTION)

- Records Deployment and Non-Deployment Events
- Included additional information at time of event:
  - Time between non-deployment events
- Pre Crash Data
  - Engine Speed (5 samples @ 1 second intervals)
  - Vehicle Speed (5 samples @ 1 second intervals)
  - Throttle Position (5 samples @ 1 second intervals)
  - Brake Switch Status (5 samples @ 1 second intervals)

Fourth Generation SDM
(2004 MY INTRODUCTION)

- Records Deployment and Non-Deployment Events
  - Some with minimum recording threshold
- Included additional information at time of event:
  - Lateral delta-v vs. time
  - Accelerator pedal position (2 samples @ 1 second intervals)
  - Cruise control status (2 samples @ 1 second intervals)
  - Transmission actual gear selected at impact
  - Steering wheel angle (5 samples @ 1 second intervals)
  - Antilock brake system status (5 samples @ 1 second intervals)
  - Door Status (closed, ajar, open) at impact
  - Tire pressure low lamp status at impact
  - Headlamp status at impact
- SDM-C – Number of vehicle data parameters reduced

EDR Definitions

- **Volatile Memory**
  - A type of memory that does not retain it's contents after power is lost
- **Non-Volatile Memory**
  - Memory that will retain it's contents after power is lost

EDR Definitions

- **Deployment Event**
  - An event that resulted in a commanded deployment by the air bag sensing system
- **Non Deployment Event**
  - An event severe enough to cause the SDM's crash sensing algorithm to "enable" or "wake up" but not severe enough to deploy the air bags
- **Deployment Level Event**
  - An event that resulted in a decision to deploy the air bags by the air bag sensing system, but a deployment had been previously commanded

Deployment Event

- A deployment event cannot be overwritten or cleared from the SDM
- Typically the SDM can store up to two different deployment events

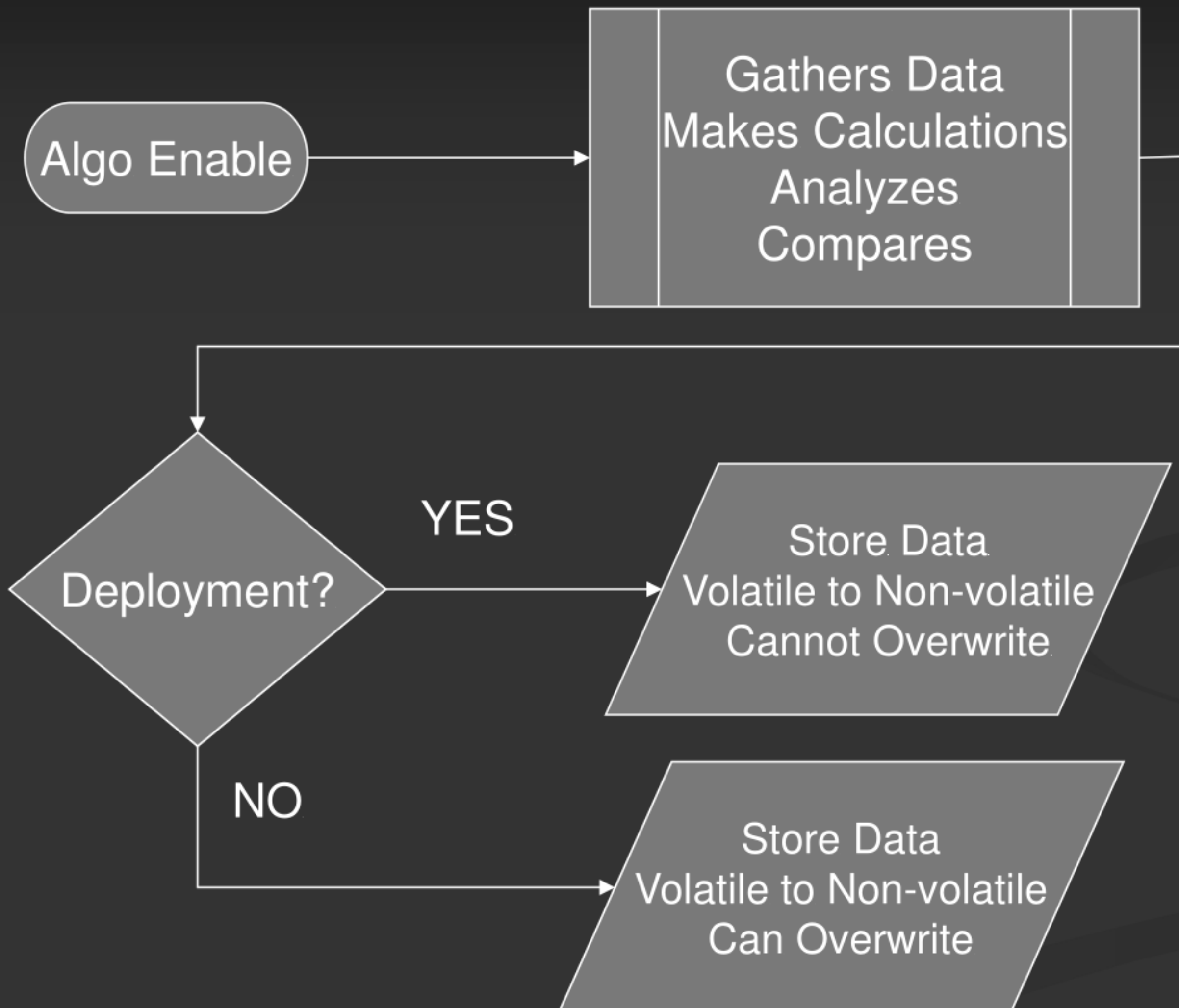
Non-Deployment Event

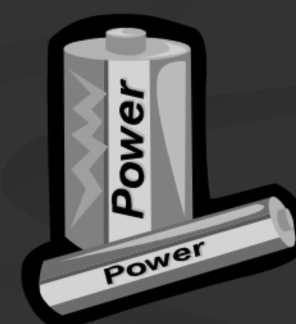
- **A non-deployment event can be overwritten by an event that has a greater recorded velocity change**
  - In some SDM types, a non-deployment event may be overwritten by the next ND event regardless of severity
- **A non-deployment event can be cleared by the SDM after sufficient ignition cycles**
- **The non-deployment event file may be locked if a deployment event happens within 5 seconds of the non-deployment event**
- **The non-deployment area may be used to store a second "deployment level" event**

Application of EDR Data to Field Events

- Questions to answer can be broad or specific
  - Examples
    - Why didn't the air bag deploy?
    - Did the system function as intended?
    - Why did only one bag deploy?
- EDR Process – how and when is data written
  - In response to a roadway hazard
  - Data is objective

Data Recording Process





Power loss can result in partial or no event record

Applying EDR Data to a Crash

- Step One
  - Is the EDR data recorded for "my crash" or the particular event being analyzed?
- Step Two
  - Which crash does the data apply to?
    - Single crash – not an issue
    - Multiple events – an issue
      - Knowing the process for writing data is essential
      - Making use of multiple event counters
- Step Three
  - Is the EDR data in harmony with the other available information
  - EDR is an important tool in the analyst's tool box
  - It is but one tool

Sources of Information

Analyzing a Field Event

- **Police Report**
- **Witness Statements and interviews**
  - Driver
  - Occupants of the subject vehicle
  - Bystanders
  - Occupants of other vehicles
- **Vehicle Photographs**
  - Subject vehicle
  - Adverse vehicle
- **Scene Photographs**
- **Crash Reconstruction**
- **Tech2 scan tool interrogation**
- **EDR Data**
- **Medical Records**

When Should an Air Bag Deploy?

- Sensing system is developed using data during vehicle development
- During an event the sensors react to the inputs experienced at their locations
- The sensors make a decision by comparing the inputs from the event being analyzed with thresholds that were determined by the data from the tests used to develop the air bag system
- The sensors deploy the air bags if they predict that the event will be severe enough for an air bag deployment

Sensing Decision Is Not Determined By:

- **Vehicle Speed Prior to the Collision**
  - Can Influence Crash Severity
- **Delta-V of the Crash**
  - Crash Severity is Also Influenced by the Time to Reach the Delta-V
- **Barrier Equivalent Velocity of the Crash**
  - Good tool for estimating magnitude
  - Limited if only one of two or more vehicles is available
  - Understand the ramifications of subject vehicle crush profile

EDR Summary

- **The EDR is a tool to help understand what happened during an event**
- **Additional factors to help understand an event may include such items as:**
  - crash report
  - physical damage to the vehicle
  - occupant injuries
  - physical damage to the adverse vehicle/objects involved in the collision
  - information from the scene of the collision
- **The EDR data can be used for more than understanding the air bag system performance**

Example of EDR Application

- 2005 MY Saab 9-7 Sport Utility
  - Dual Stage Frontal Air Bags
    - Automatic passenger supplemental inflatable restraint (PSIR) suppression
  - Side Curtain Air Bags
  - Crash sensing
    - SDM-DS
    - Two electronic front sensors
    - Rollover Sensing Ros-A

- Single Vehicle Single Occupant Crash
  - Driver lap and shoulder belted, coded "possible injury, none visible"
  - Off roadway, multiple tree impacts
  - An unsubstantiated adverse vehicle crossed the centerline and forced the SAAB 9-7 off the road to the right
  - Speed limit on roadway = 55 mph
  - Daylight, cloudy but dry

- Questions
  - Why didn't the passenger air bag deploy?
  - What commanded the roof rail air bags to deploy?

SDM EDR Data

Multiple Events

Vetronix CDR CRASH DATA RETRIEVAL SYSTEM

Multiple Event Data

An Event(s) Preceded the Recorded Event(s)	No
An Event(s) was in Between the Recorded Event(s)	Yes
An Event(s) Followed the Recorded Event(s)	Yes
The Event(s) Not Recorded was a Deployment Event(s)	No
The Event(s) Not Recorded was a Non-Deployment Event(s)	Yes
Associated Events Not Recorded	3

System Status At 1 second

Left Front Door Ajar	No
Right Front Door Ajar	No
Left Rear Door Ajar	No
Right Rear Door Ajar	No

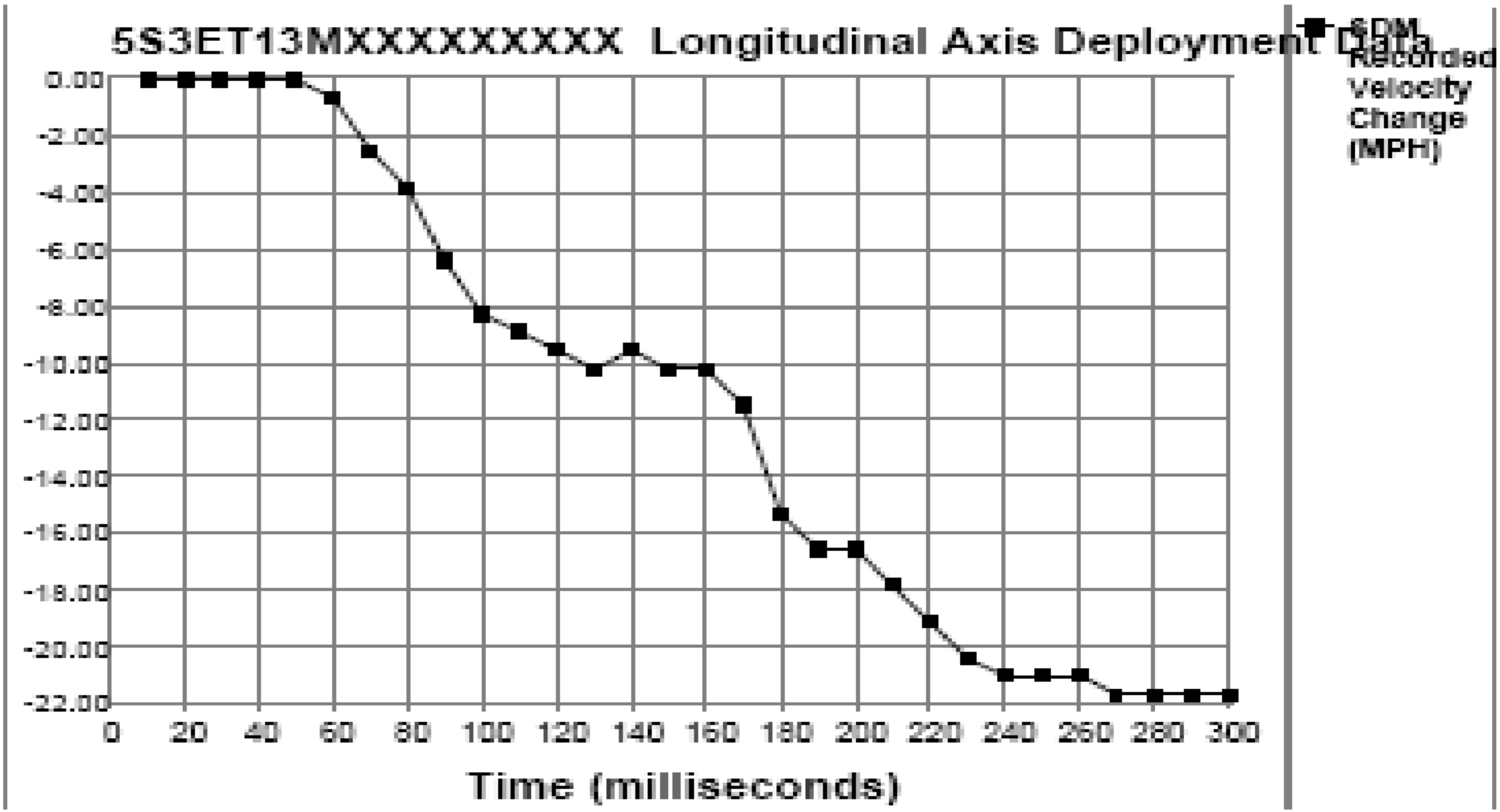
Pre-crash data

Parameter	-5 sec	-4 sec	-3 sec	-2 sec	-1 sec
Vehicle Speed (MPH)	55	55	55	55	53
Engine Speed (RPM)	1792	1664	1664	1664	1664
Percent Throttle	16	10	10	10	10
Brake Switch Circuit Status	not applied	not applied	not applied	not applied	not applied

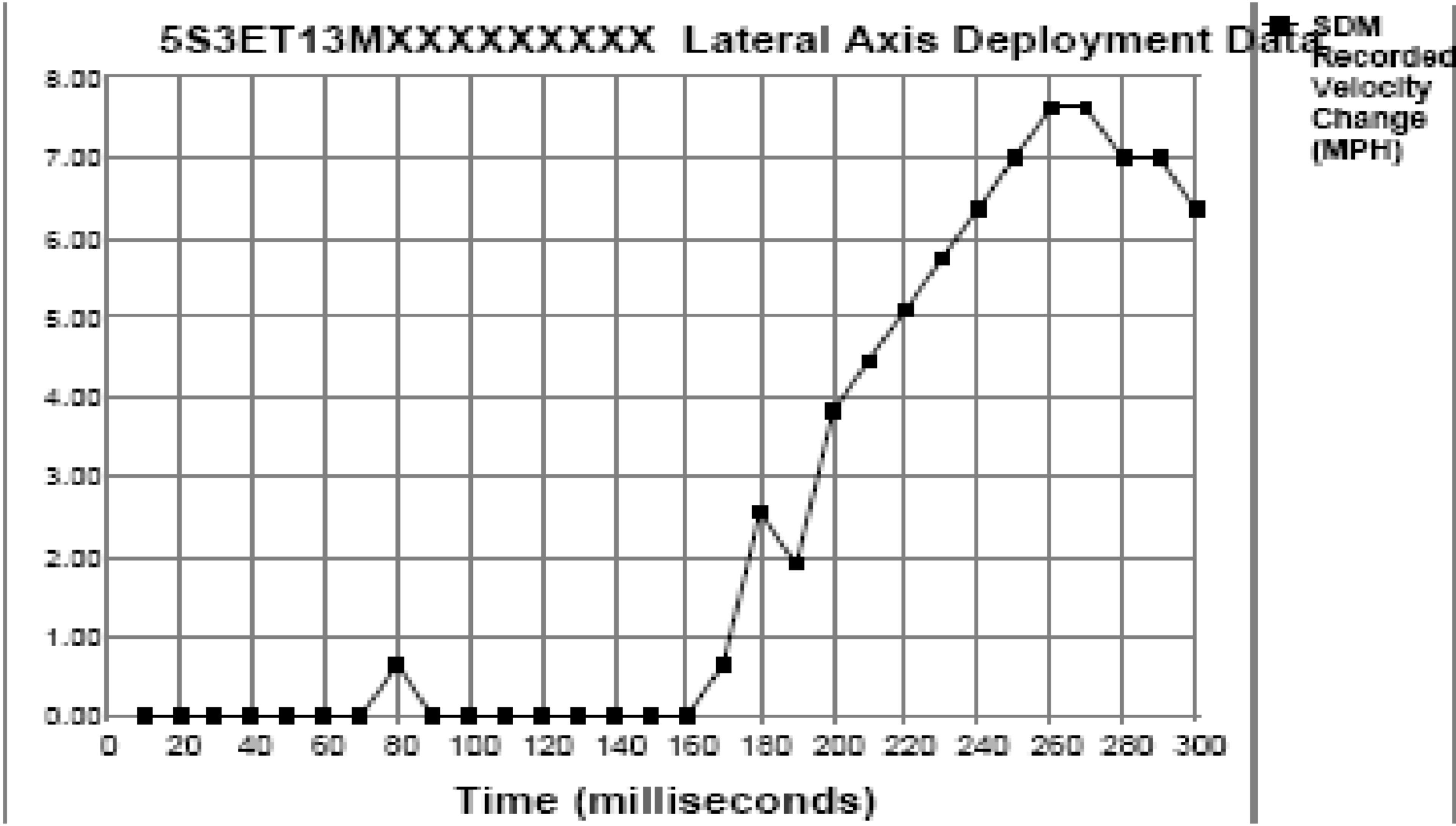
Deployment Event EDR Summary

	First Deploy	Second Deploy
SIR Lamp	Off	Off
Cycles, Investigation	1260	1260
Cycles, Event	1259	1259
Driver Belt Switch Status	Buckled	Buckled
Passenger Belt Switch Status	Unbuckled	Unbuckled
Dr. Seat Pos.	Rearward	Rearward
Pass. Seat Pos.	Rearward	Rearward
Automatic PSIR Suppression	Suppressed	Suppressed
AE to Dr. 1st stage	21.25 ms	0
AE to 2nd stage	Disposal	0
Dr. 1st stage commanded	Yes	No
Dr. 2nd stage commanded	Yes	No
Dr. SIAB commanded	No	No
Dr./Pass Pretens commanded	Yes	No
Rollover Sensor Status	Invalid	0-1/4 turn
AE to RRAB Command	N/A	318.75
Dr./Pass RRAB commanded	No	Yes

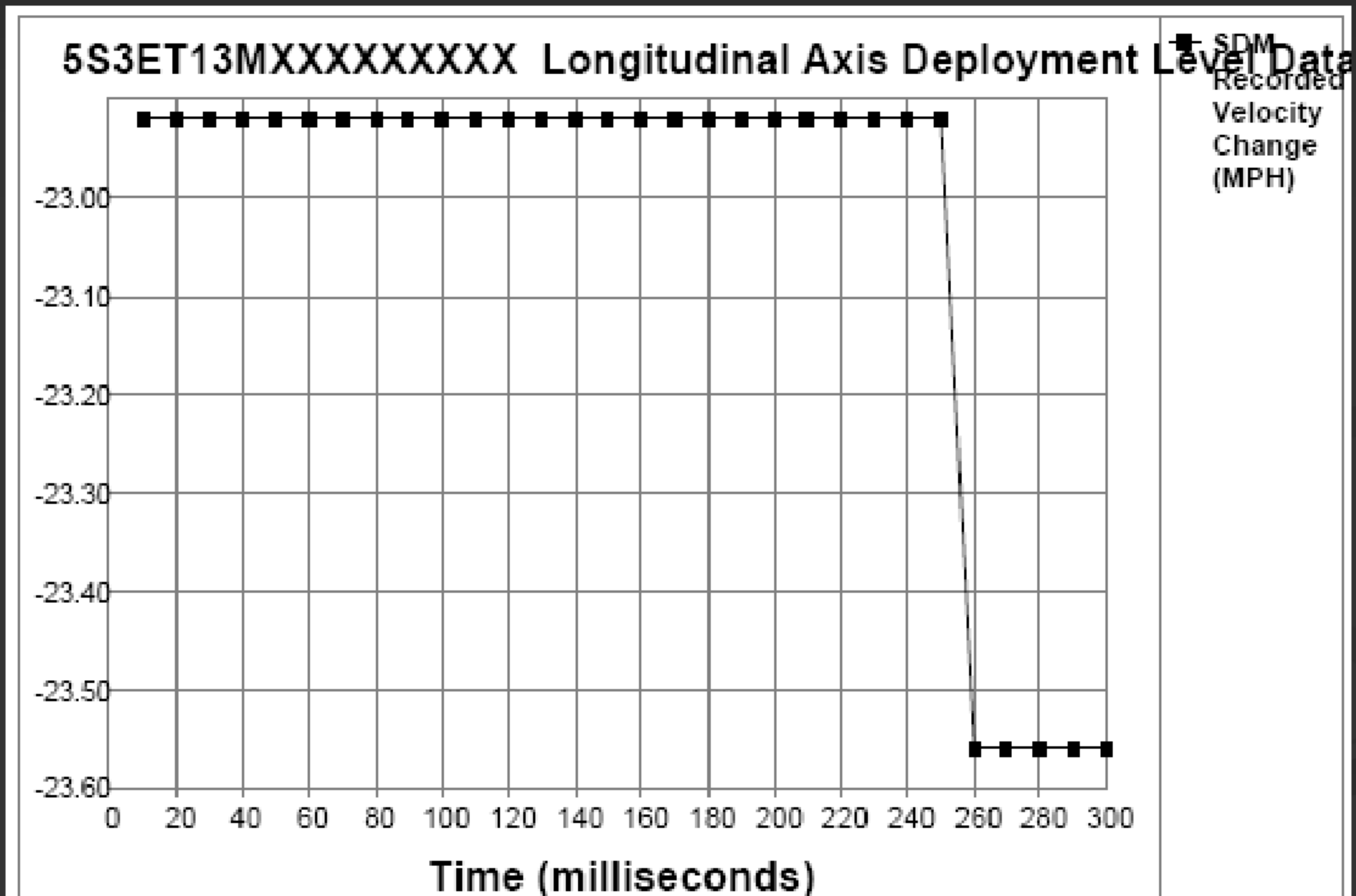
Longitudinal Delta-V



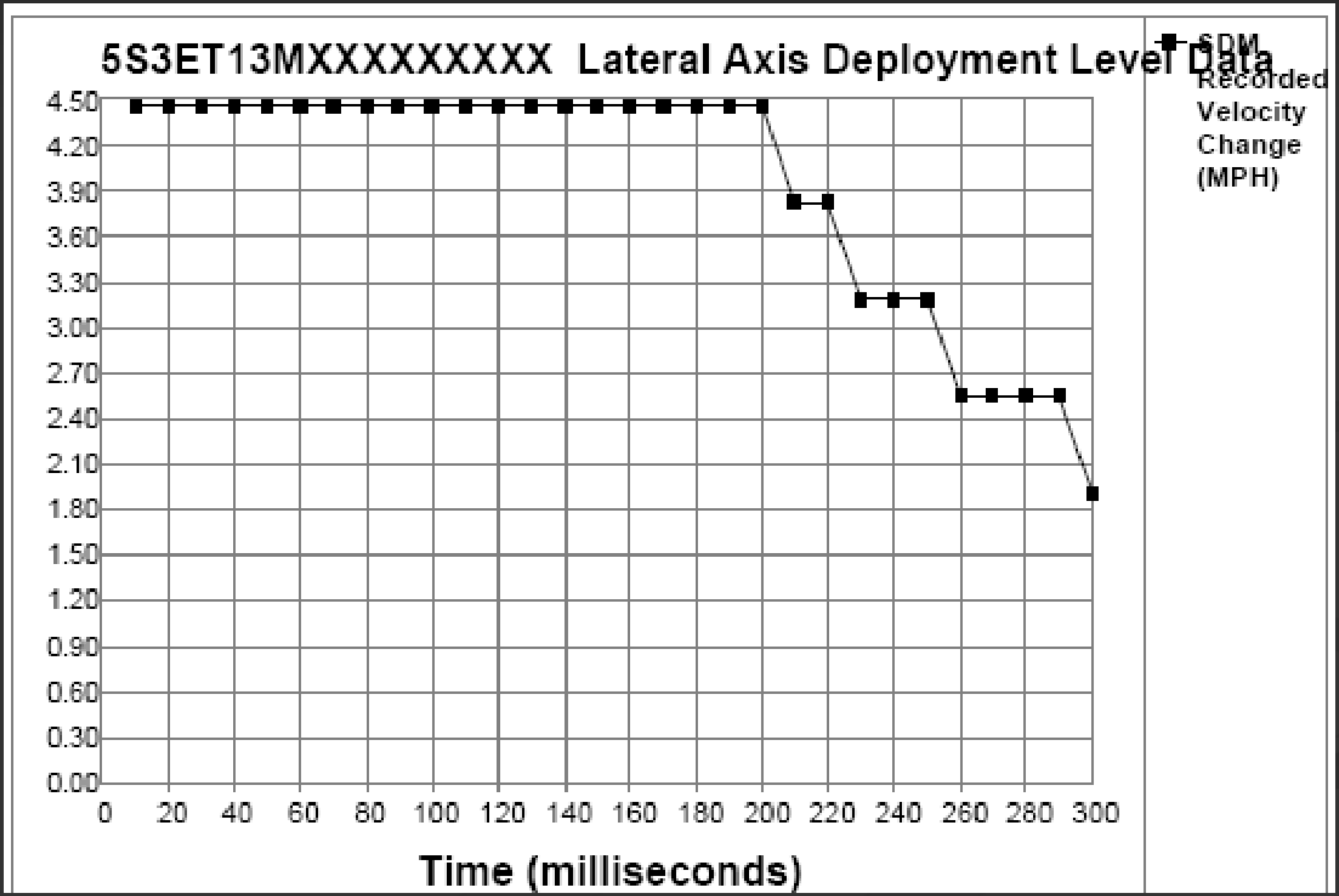
Lateral Delta-V



Second Deployment Event Longitudinal Delta-V



Second Deployment Event
Lateral Delta-V



2005 MY Saab 9-7

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2005 MY Saab 9-7

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Example Two: SRX Rollover

D/A 04/26/06

- *Date of Crash* : April 26, 2006
- *Time of Crash* : approx. 9:30 AM
- *Vehicle* : 2006* Cadillac SRX *with modified 2007 components*
- *Crash location* : Milford Proving Ground *Road Course*
- *Occupants* : Driver and right front passenger
- *Reported Injuries* : Driver (Minor) , Passenger (None)
- *Test purpose* : Transmission Calibration Verification

- Question
  - Did this new technology function as intended?

SRX Rollover

Road and weather conditions

- Dry asphalt surface
- "One-way" travel direction (width of road approx. 35 ft.)
- Typical off-road soil shoulder composite soil
- Curves and hills in this section of course
- Concrete "rumble" strips present at selected curves
- Daylight and clear

SRX Rollover

Observations

- ESC (Electronic Stability Control) manually disabled (Off)
- Off road "soil" trip
- Trip speed was approx. 10 -14 mph
- ¼ roll : driver side leading
- Loss of control due to driver input, aggressive driving schedule, and road course terrain
- Rollover trip occurred on an incline (uphill)

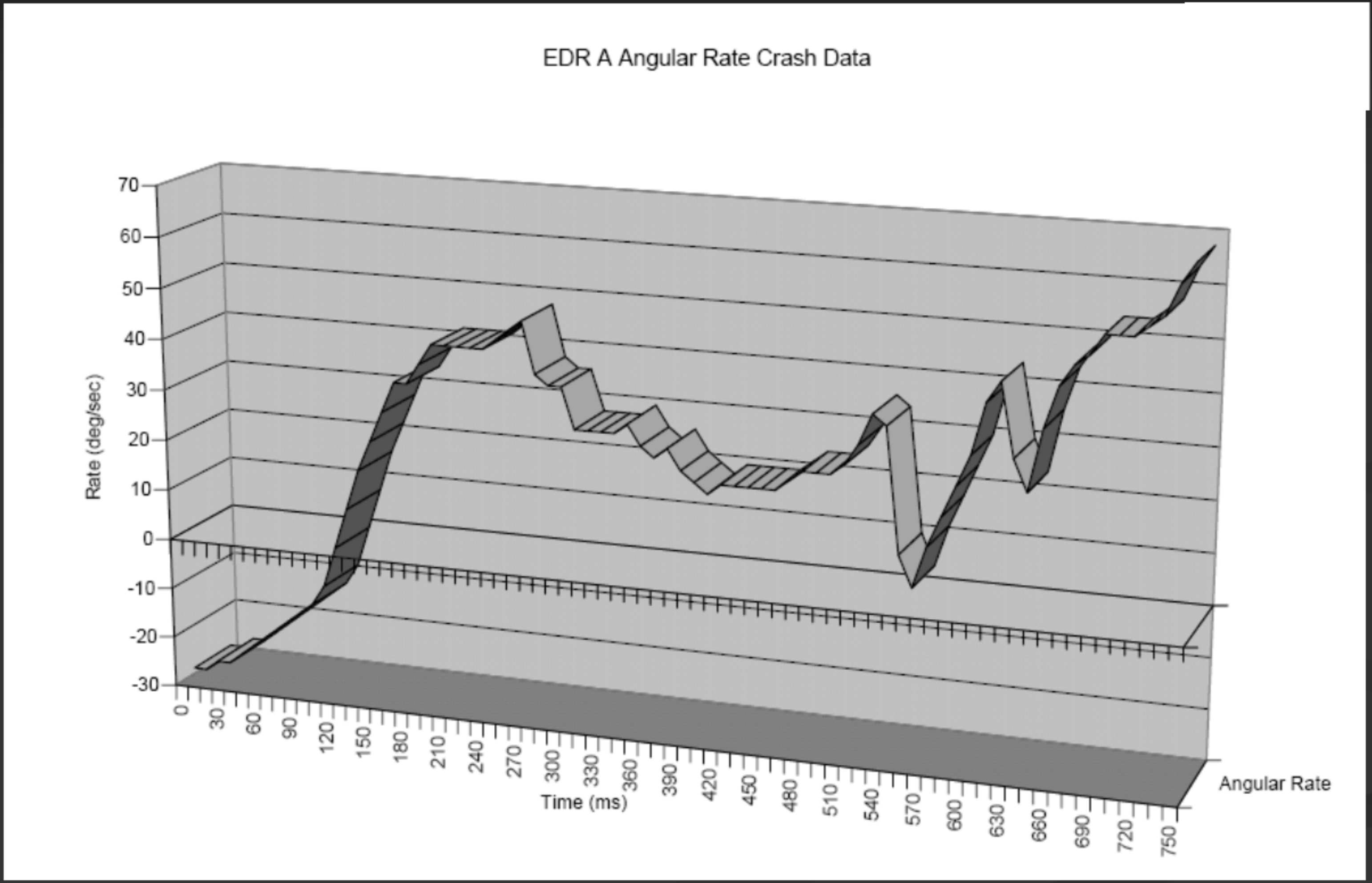
SRX Rollover

EDR Summary

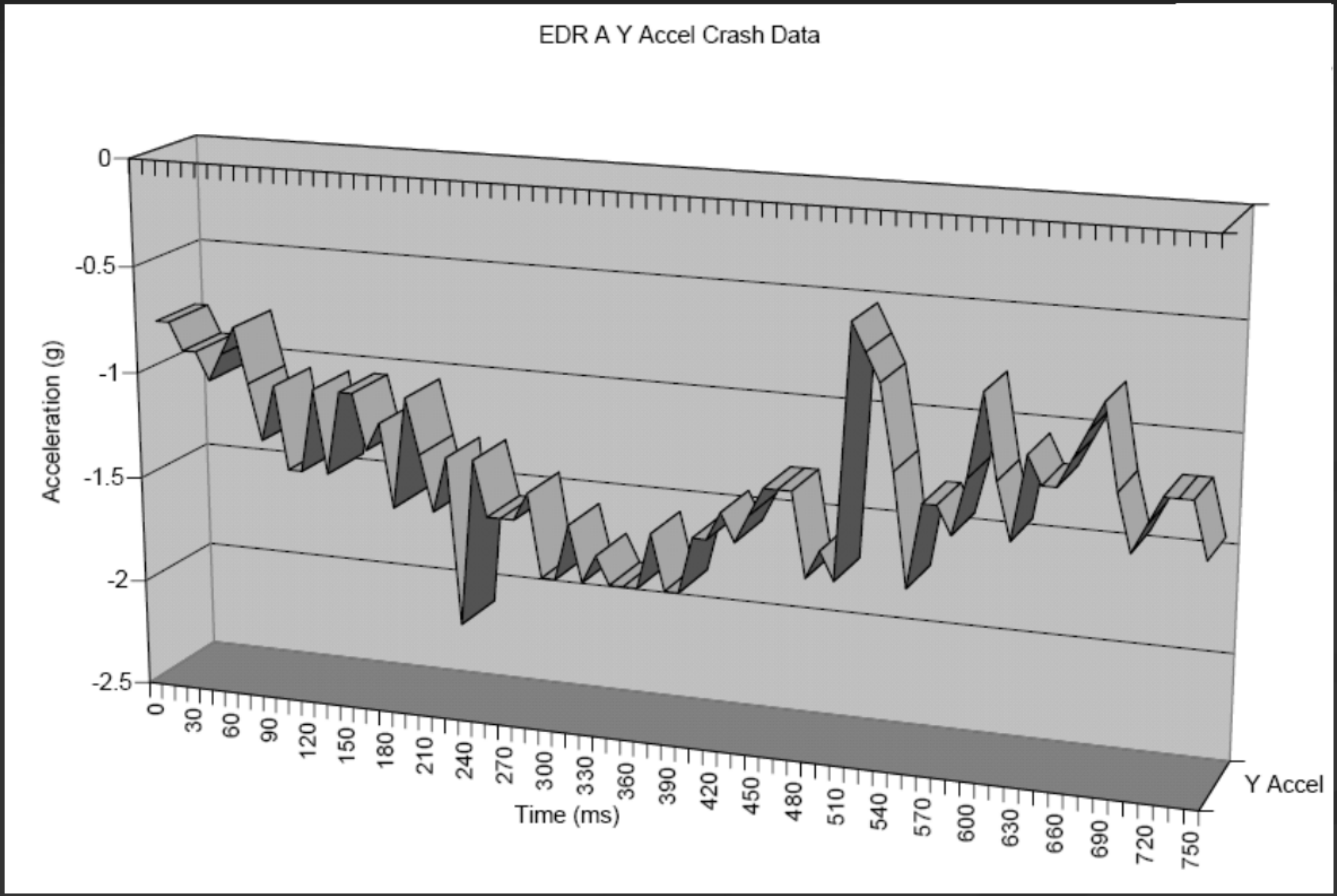
- **ROS Data**
  - Rollover Event
  - SDM sync counter = 1350
  - Vehicle speed prior to ROS AE = 54 mph
  - AE to rollover bag command = 4.180 sec.
  - Deploy off battery power
  - ROS in development mode
  - REC mode deployment

- **SDM Data**
  - Pre-crash data about -.5 second
    - speed = 53 mph
    - engine RPM = 4736
    - % throttle = 27
    - brake = off
  - SDM sync counter = 1350
  - Dr. & Pass. = buckled
  - Side bags commanded due to rollover event
  - SDM indicated ROS AE to RRAB command = 4.200 sec.
  - Dr. & Pass. pretensioners and RRAB commanded = YES

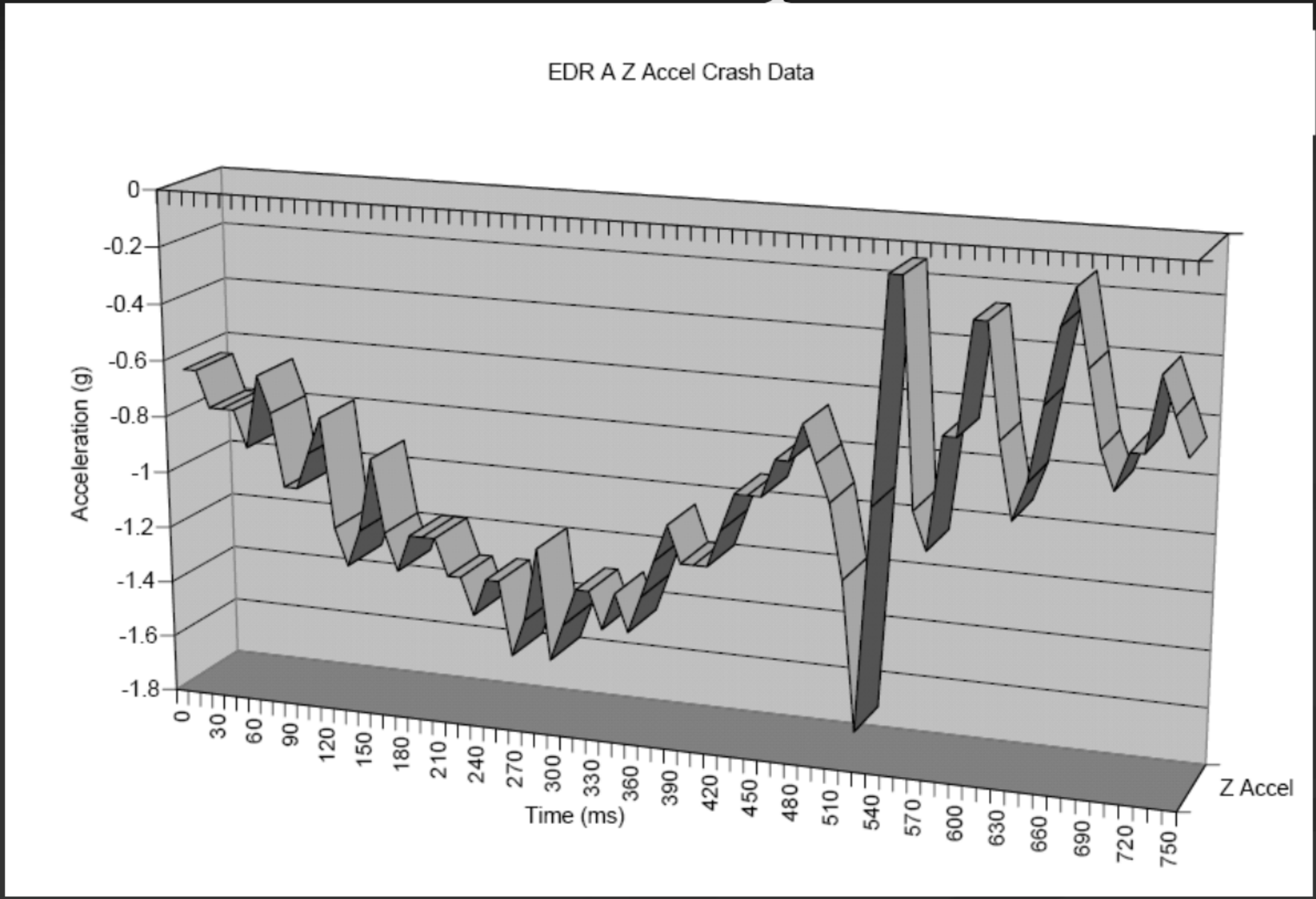
ROS Angular Rate Data



ROS Lateral Input Data



ROS Vertical Input Data



SRX Rollover

Crash scene photos

Final Rest Position

SRX Rollover

Crash scene photos

Both side curtains deployed

SRX Rollover

Crash scene photos

Vehicle up-righted at scene

Note that this damage was caused by tow truck cable during up-righting.

SRX Rollover

Photos of damaged SRX

Driver side

Relatively <u>minor</u> damage:

- Left front wheel
- Left rear wheel
- Driver window
- Side view mirror
- Fender and doors

SRX Rollover

Photos of damaged SRX

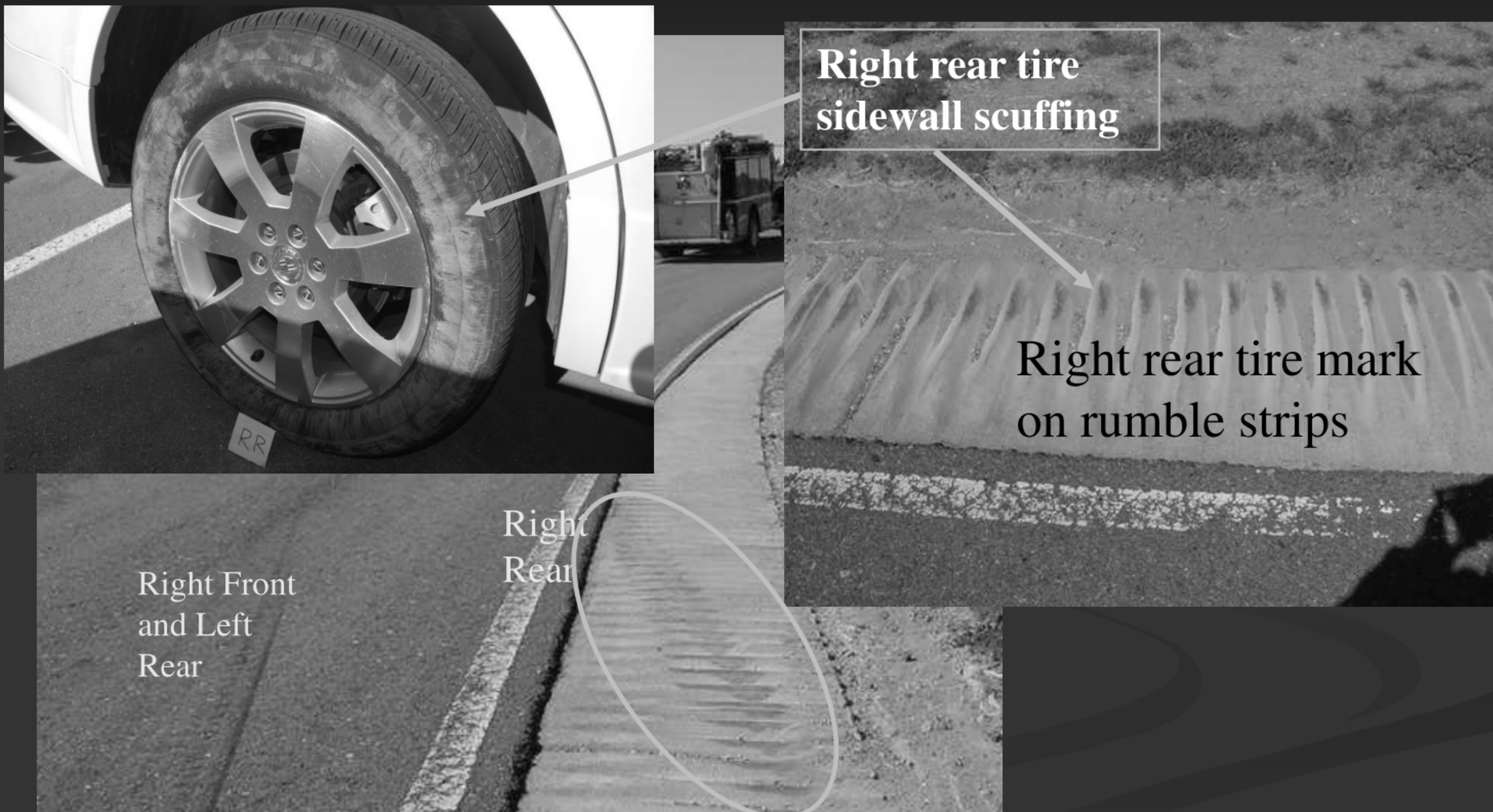
Driver side

SRX Rollover

Tire mark and tire rut identification

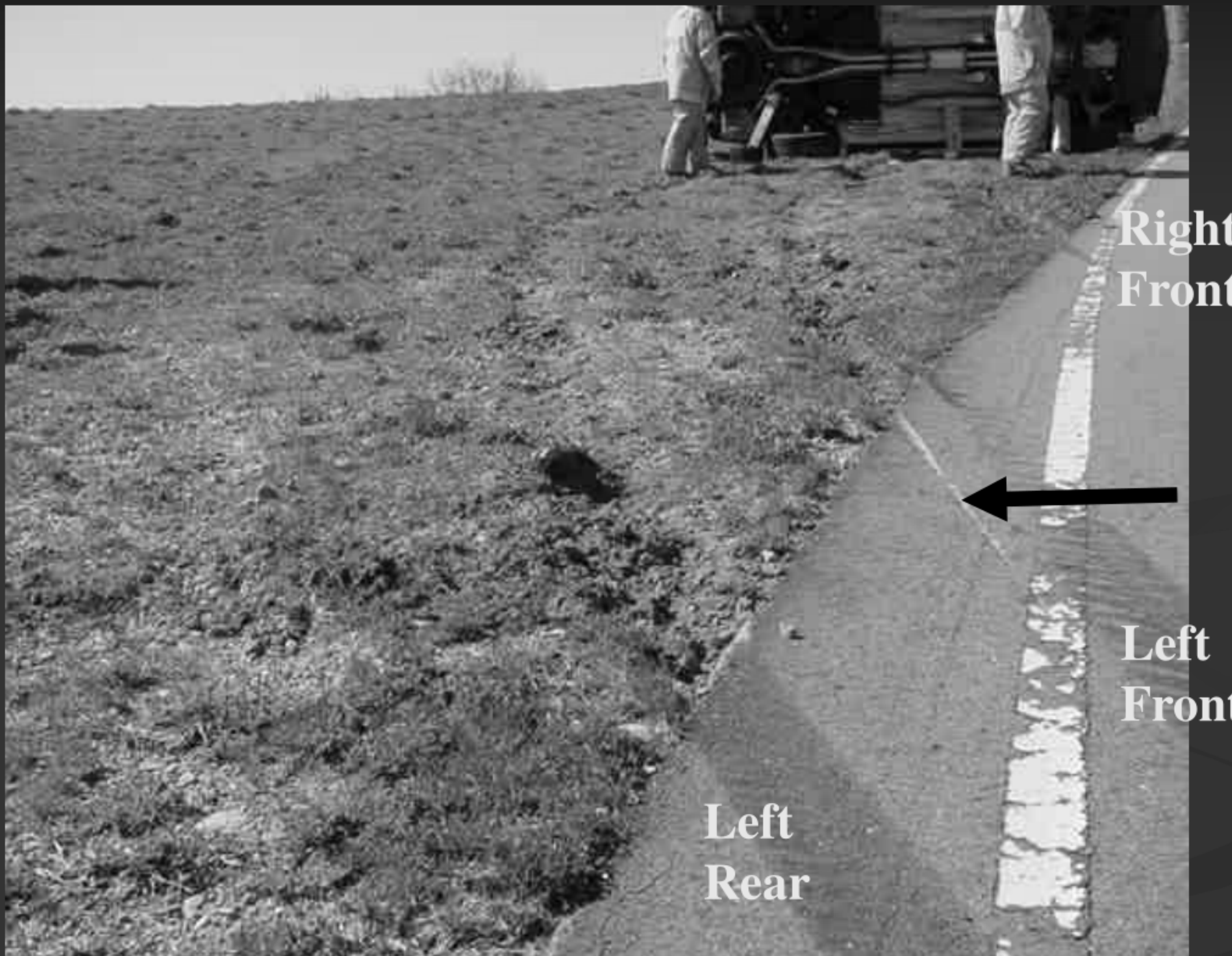
SRX Rollover

Tire mark identification



SRX Rollover

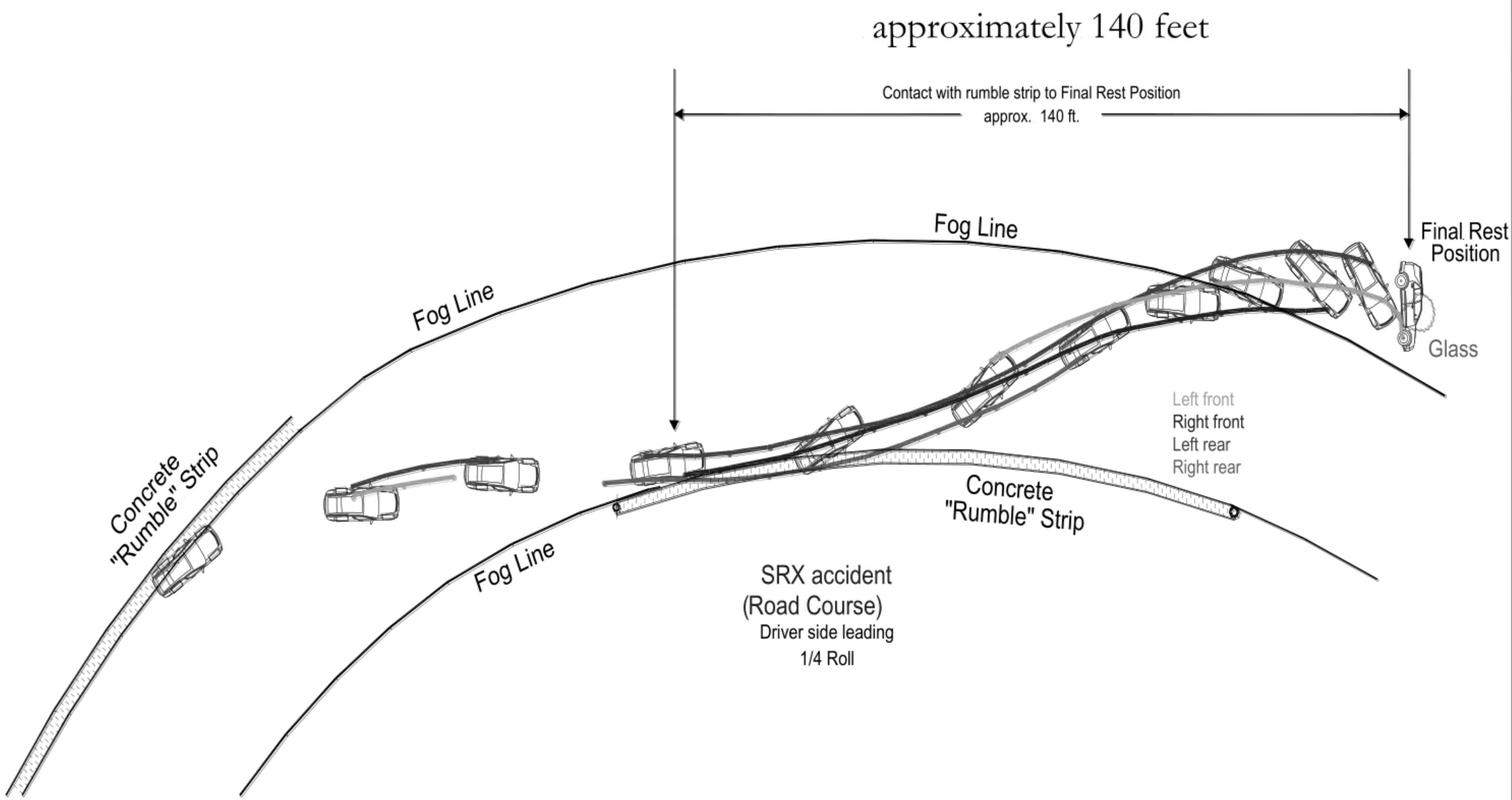
Asphalt gouge and tire mark identification



Asphalt gouging from Left Front rim

SRX Rollover

ROS Algorithm Enable area (near rumble strip)

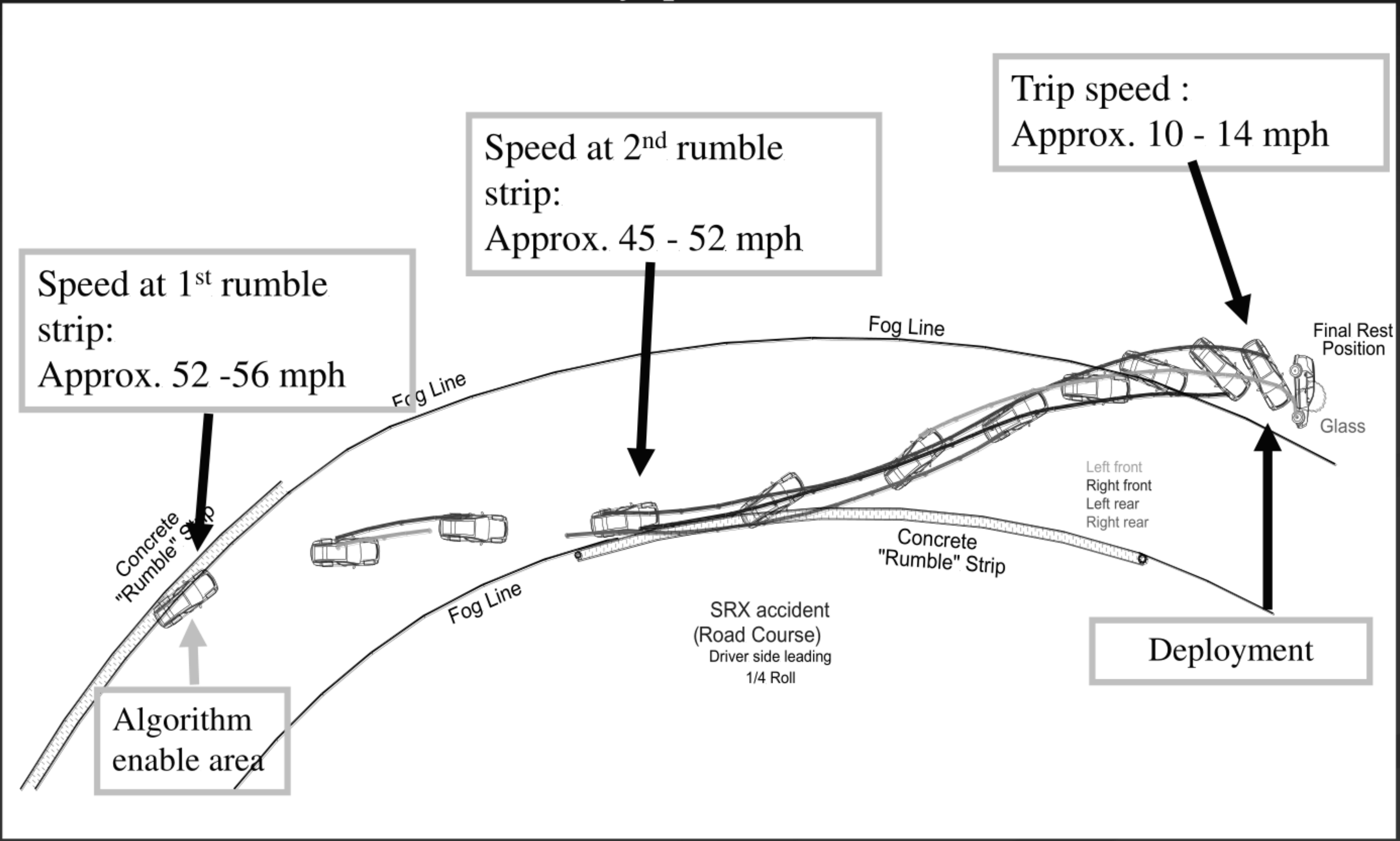

approximately 140 feet
Contact with rumble strip to Final Rest Position
approx. 140 ft.
Fog Line
Fog Line
Final Rest
Position
Glass
Concrete
"Rumble" Strip
Left front
Right front
Left rear
Right rear
Concrete
"Rumble" Strip
Fog Line
SRX accident
(Road Course)
Driver side leading
1/4 Roll

SRX Rollover

Scene diagram overlaid onto enlarged aerial section

SRX Rollover

Preliminary speed calculations



THE END