Investigation and Interpretation of Black Box Data in Automobiles

A Guide to the Concepts and Formats of Computer Data in Vehicle Safety and Control Systems

William Rosenbluth

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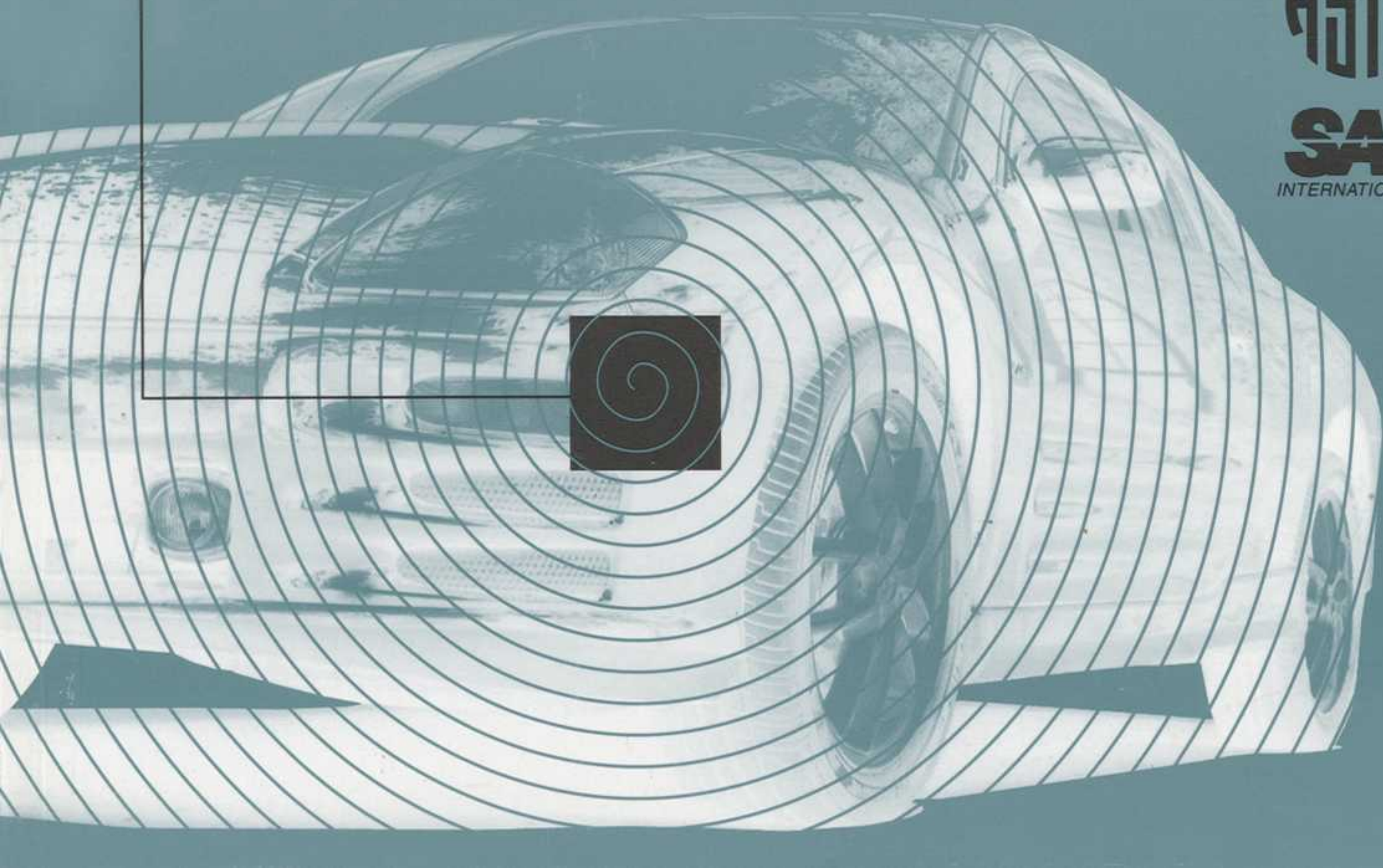

Monograph 4
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NOTE: This monograph does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this manual to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

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Dedication

THIS BOOK IS DEDICATED to my wife, Jean Joy Rosenbluth. Her strong belief in me, and her continuous encouragement, patience, and ever present support in the face of manifold adversities and diversions, made possible the development of the data skills and the laboratory where I accomplished much of the work and learning chronicled herein. That foundation ultimately made this book possible.

Foreword

THIS PUBLICATION, *Investigation and Interpretation of Black Box Data in Automobiles: A Guide to the Concepts and Formats of Computer Data in Vehicle Safety and Control Systems*, was sponsored by Committee E30 on Forensic Sciences and the Society of Automotive Engineers, Inc. This is Monograph 4 in ASTM's monograph series.

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Steven Rosenbluth, The Jim Henson Company, Inc., Hollywood, CA, for his pioneering development of electronic data interfaces, interrogation software, and original data interpretation formats, all of which have allowed us to perform multiple comparative EEPROM crash-data analyses, for both simulated and real crash events.

Contents

Preface

CERTAINLY NO ONE WISHES FOR AN AIRCRAFT DISASTER, but when one occurs, everyone wants to know why. In the analysis of aircraft disasters, among the primary investigative tools used by the FAA and NTSB are the continuing data recorders on the aircraft itself. Those data recorders, the cockpit voice recorder (CVR) and the digital flight data recorder (DFDR) shown in Fig. P1, are colloquially known as *black boxes* and are often the focus of intensive searches at the crash site because of the valuable information they may contain about conditions before and during the last moments of aircraft operation. The CVRs and DFDRs save their data in media that survive most crashes, and their information and operational parameters[1] can help identify human error, equipment malfunction, or unexpected weather anomalies. But, not all situations can be predicted. For example, in the Oct. 25, 1999 Learjet crash that killed golfer Payne Stewart and five others, investigators did not find any CVR voice information because it operated as a 30 minute tape loop. Unfortunately, the likely decompression incident happened in the first 30 minutes of flight, hours before the crash-caused loss of power stopped the tape loop. By that time, all persons were unconscious, the valuable cockpit conversation(s) were overwritten, and the only data on the CVR were cabin pressure and stall warnings as the plane ran out of fuel (Moss 1999; Lunsford 1999; Hembree 1999; NTSB Advisory 1999; NTSB Investigation undated).

Technology advances within the past ten years have allowed increasingly sophisticated nonvolatile electronic data storage capabilities on automobiles and trucks. Among the first were electronic odometers, which saved the vehicle cumulative mileage, even if the battery was disconnected. Application of nonvolatile electronic data storage was then incorporated to assist with the diagnosis and repair of intermittent electronic faults that would otherwise be difficult or impossible to diagnose. Systems having the capability to incorporate nonvolatile electronic data storage include engine fuel management (EFI), antilock braking (ABS), automatic traction control (ATC), cruise control (CC), air bags (SRS), and seat belt tensioners (ETR). Figure P2 shows a simple example of ECU controllers for the ABS and SRS.

One byproduct of the incorporation of nonvolatile electronic data storage for diagnosis and repair is the utility of this electronically saved data to assist land vehicle investigators in determining vehicle conditions before and during an accident in a way unavailable by previous post accident mechanical analysis techniques. However, because the original intent of this electronically saved data capability was to assist repair, and not necessarily to assist accident investigation, these data are often distributed among several different units, which save data in their own formats and for their own diagnostic purposes (EFI, ABS, ATC, CC, SRS, ETR, etc.).

In each system that incorporates computer control, the assembly containing the integrated circuit microprocessor unit (MPU) is called the electronic control unit (ECU). Within the ECU, the desired nonvolatile information is saved in EEPROM.[2] This information usually includes diagnostic trouble codes (DTCs),[3] and optional par-

[1] DFDRs on commercial airlines save over 50 mandatory and 30 optional parameters. A reference showing a complete list of DFDR parameters, including a comparison to known automotive parameters, is shown in Appendix E: "A Comparison of Recorded Data Parameters, Aircraft versus Automotive Black Boxes."

[2] EEPROM—Electrically Erasable Programmable Read Only Memory. EEPROM is fabricated using a special semiconductor construction that allows it to retain previously stored data even when the battery is disconnected. A similarly functioning technology, Flash Memory, is also used for this purpose.

[3] Often called *error codes*.

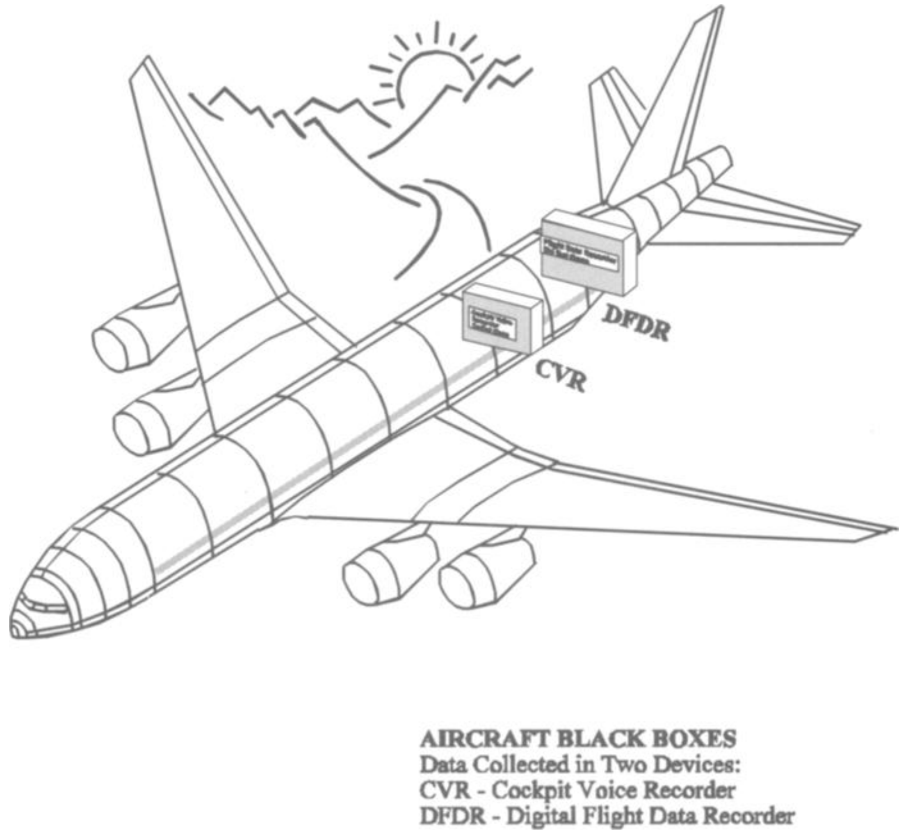

FIG. P.1—Aircraft data recorders.

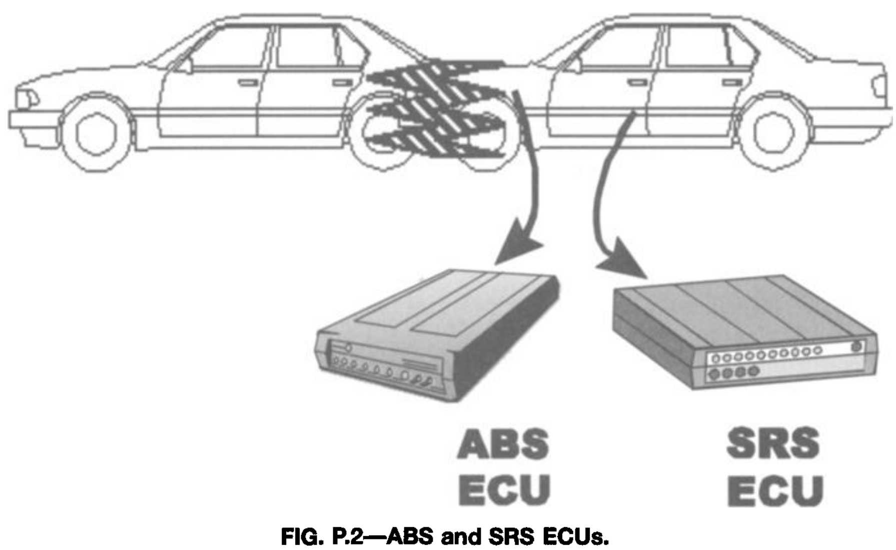

FIG. P.2—ABS and SRS ECUs.

ametric data. Because EEPROM is nonvolatile, it retains its data even when the battery is disconnected. EEPROM data are downloaded from a vehicle ECU using a scanner[4] or via a microprocessor interface, in much the same way as a credit card terminal is used to query a central data bank to authorize a credit purchase. This concept is shown in Fig. P3. There are two levels of stored data: repair-level DTCs and engineering-level

[4] Scanner—Small hand-held microprocessor capable of sending serial data commands to a vehicle ECU and then receiving and selectively recording/interpreting ECU serial response data.

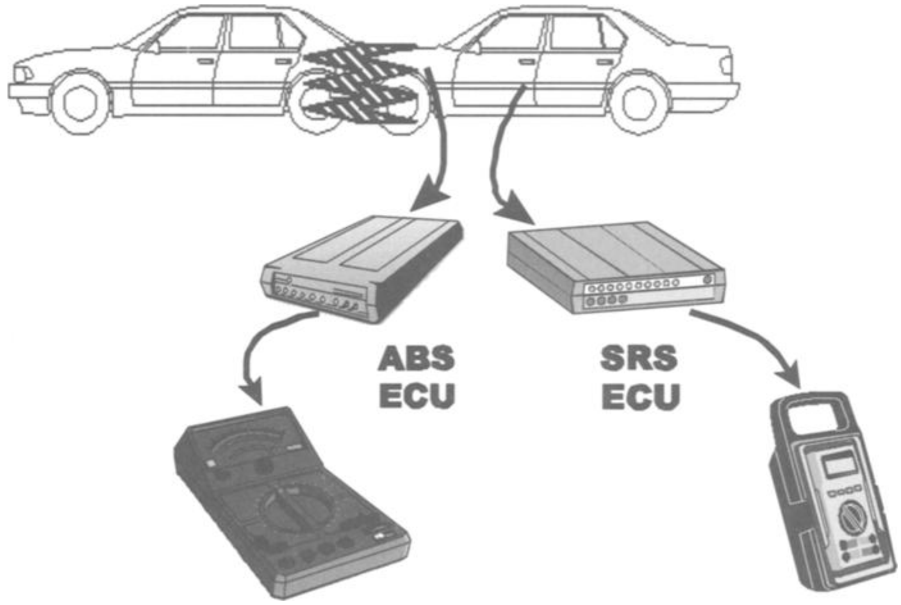

FIG. P.3—ABS and SRS ECUs with dedicated scanners.

parametric crash data. Generally, repair-level scanners cannot access engineering-level data, whereas engineering-level scanners can access all data.

As we have discussed above, certain crash-related data may be stored in the EEPROMs of several vehicle ECUs, requiring the use of several scanners, one dedicated to each type of system ECU, to acquire a complete set of crash data. This is shown schematically in Fig. P3. Newer vehicle models[5] utilize advanced scanners that often incorporate multi-system interrogation functions in a single unit.

Thus, the concept of vehicle black box data is actually an umbrella term, which implies using data components that are obtained by interrogating several different system units that can be assembled to provide a set of electronically saved data useful to the accident investigator.

In addition to scanners, a laboratory computer interface can be used to accomplish the EEPROM download process for both repair and engineering-level data. Sometimes, this method provides more detail than field scanners can provide. An illustration of a laboratory download of air bag ECU EEPROM data is shown in Fig. P4.

Engineering-level data can incorporate additional parameters such as time, ignition cycles, velocity change, pre-event velocity, acceleration profile, seat belt status, and other crash event data.

When a set of data is saved only after a certain condition or event, that data is often called a *freeze frame*, and the triggering condition is called the *event trigger*. An air bag ECU data event trigger is a crash deployment command, and the saved freeze frame data can identify crash timing, crash velocity changes, seat belt usage, etc. An ABS ECU event trigger can be any DTC, for example, a front wheel sensor malfunction DTC as caused by a crash. The saved freeze frame data can identify wheel speeds, brake apply status, ignition cycles, etc., at the time the DTC was set.

If a crash event has triggered both of the above freeze frame examples, one can see how the combined set of saved data can present an extended overview of vehicle conditions at a critical moment, such as the instant of the crash.

The balance of this book identifies where and how to find various data parameters, as saved in various freeze frames, which have multiple formats, and shows how to interpret and combine them so their sum can present a vehicle condition overview that can provide significant additional information when compared to traditional post accident mechanical analysis techniques. As we continue this investigation, we will

[5]Models starting with the 1996 model year are mandated to have OBD-II compliant scanners, many of which incorporate multi-communication protocols and multi-system functions in a single integrated scanner unit.

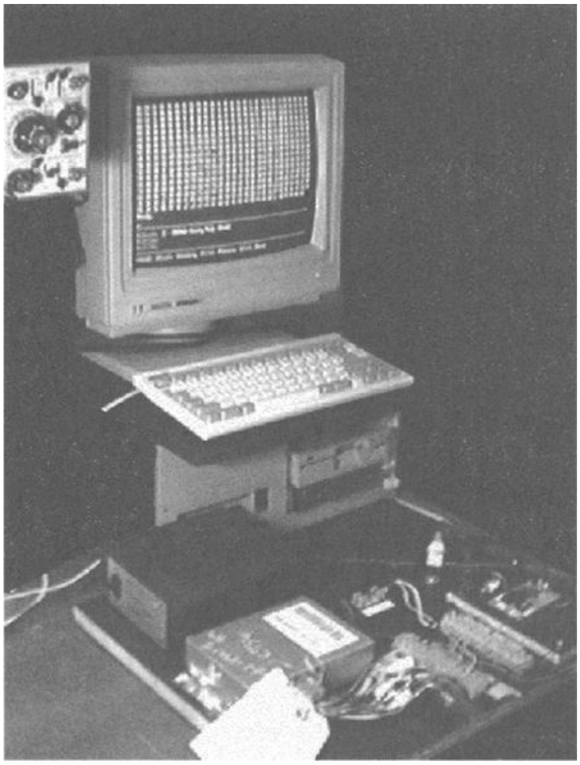

FIG. P.4—Laboratory download of an SRS ECU.

also cover some mathematical structures, basic Newtonian physics, and basic electronic circuits. These concepts are then integrated into several case studies.

Also included are several appendices with information useful to investigators in this field:

Appendix	Title
A	Glossary of Terms and Conversion Factors Used in Vehicle Data Systems
B	Scan Tools, Scanners, Bus Interfaces, and Manufacturer Contacts
C	Government Standards and Regulations (CARB, DOT/NHTSA, EPA)
D	Industry Standards and Specifications (SAE, ASTM, ISO, etc.)
E	Comparison of Recorded Data Parameters, Aircraft versus Automotive Black Boxes

In conclusion, the reader should be aware that, just as with aircraft CVR and DFDR data, the inexorable progress of time and technology will serve to make the set of available crash event data increasingly more complete and more useful. These advances will almost certainly incorporate increasingly more complex data formats and sources, so the methods and formats discussed herein will probably be considered only a primer for future investigators probing electronically saved data.

Background and Evolution of On-board Vehicle Data, Diagnostics, and Communications Capabilities

1

1.1 INTRODUCTION TO VEHICLE ELECTRONIC FEEDBACK CONTROL

TECHNOLOGY ADVANCES WITHIN THE PAST 15 YEARS have allowed increasingly sophisticated nonvolatile electronic data storage capabilities on automobiles and trucks. This sophistication has come about because of a combination of governmental regulations requiring more precise control of emissions and safety systems, and the cost benefits and inherent precision available with the use of embedded microcomputer (integrated circuit) feedback systems to control formerly all-mechanical vehicle systems. For four decades before that era,[1] all-mechanical systems were reasonably constant in concept and components. However, electronic feedback systems had the advantage of being self-calibrating and self-aligning over the same period of usage in which purely mechanical systems often wandered far out of acceptable tolerances[2] and needed frequent tune-ups. In this new era, self-calibration was essential because federal emission standards mandated that the emissions portion of vehicle drive trains stay in calibration for 50 000 miles or more, and, if a miscalibration was detected, provide a warning indication (lamp) to the operator. The electronic systems made it easy to do that without frequent tune-ups, as well as having the inherent ability to incorporate programmable warning and alarm limits, depending on vehicle platform and regulation year.[3] Early electronic systems required battery power to save continuing data such as hard and intermittent diagnostic trouble codes (DTCs) and running calibration data.[4] Yet, if battery power was lost, all prior saved DTCs and calibration data were lost. When that happened, any DTCs generated by an intermittent problem would not be detected until the vehicle was again run and the problem reoccurred. Additionally, for every battery power loss, engine systems had to "recalibrate themselves" and radio station settings had to be reprogrammed. Starting in the mid-1980s, a new technology was introduced into vehicle systems, Electrically Erasable Programmable Read Only Memory (EEPROM) (Kendall 1987). EEPROM, developed in the 1970s as an adjunct to microcomputer semiconductor memory development, is nonvolatile, which means that after data are written to it, the data are retained even when its power source is disconnected. This technology avoided engine recalibration cycles and lost radio station settings when a battery was changed. The first on-board automotive applications of EEPROM were in electronic odometers, which saved the vehicle cumulative mileage, even if the battery was disconnected. However, even though the cumulative mileage was saved, it could only be read with battery power applied, since the odometer readout was also electronic. In the 1990s, a product with similar nonvolatile storage characteristics, Flash Memory,[5] was introduced into vehicle systems (Intel 1996; See and Thurlo 1995). Flash memory uses an inherently simpler IC device structure for data storage than EEPROM, but, generally, it is only manipulated in multi-byte block sections, whereas EEPROM can be single-byte or block alterable.

[1]A good part of the cost benefits of large scale integrated circuits came about because of their accelerated introduction and widespread usage in military and personal computing systems in this same era. Recall that the dawn of commercial use integrated circuits came with the Intel 4004, 8008, and 8080, the 1977 TRS80, the 1979 Apple II, the 1981 IBM PC both running VisiCalc, and dBase II.

[2]One notably durable and self-aligning mechanical system was the IBM Selectric® typewriter, wherein the type ball retained alignment using cast positioning teeth which forced a correct alignment on the transport carriage, even as its steel control bands stretched.

[3]This was done by using small "calibrator" modules tailored to the particular vehicle on which a generic electronic controller was applied.

[4]The memory (RAM) that depended on vehicle battery power to save data was called Keep Alive Memory (KAM).

1.2 EXAMPLES OF ON-BOARD VEHICLE SYSTEMS WITH DATA MEMORY

The first widespread use of vehicle embedded microcomputer feedback systems, as used to control formerly mechanical vehicle systems, occurred with engine fuel management and idle speed systems. These took the form of hybrid controls, where carburetor fuel/air mixtures were controlled using pulsed solenoids whose duty cycle was determined by an electronic control unit (ECU) that monitored sensors, including the exhaust gas oxygen content and engine temperature. Later systems substituted an electrical fuel valve for the classic venturi orifice, and the fuel-charging element was then called a throttle body. Even later systems distributed the fuel injection valves at each cylinder, and these were described as port fuel injected engines. Lumped under the term electronic fuel injection (EFI), and also introduced in hybrid form in some European vehicles, electrical fuel mixture control was introduced on U.S. domestic vehicles in the early 1980s. By 1990, EFI engine management was considered by the U.S. domestic buying public to be the minimum standard state-of-the-art, and venturi carburetors were practically obsolete. A schematic of such a feedback system is shown in Fig. 1.1, where the controlled parameter is fuel quantity injected into the engine, the feedback parameters are throttle position and exhaust gas oxygen content, and the engine controller is an ECU, variously called an electronic

[5]Introduced by Intel as ETOX™ flash memory in 1988.

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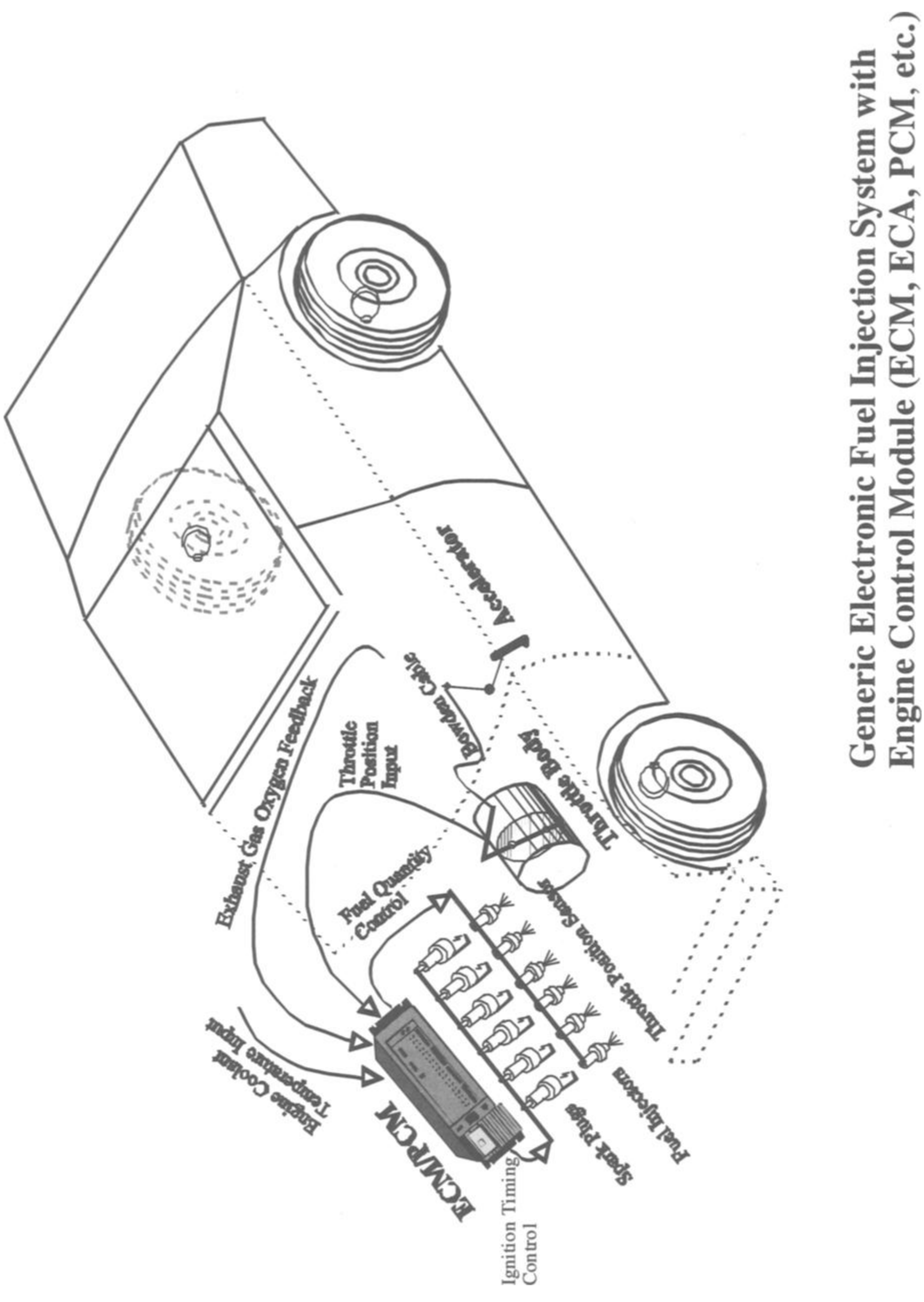


FIG. 1.1—Engine ECU using exhaust gas and throttle feedback to control fuel mixture.

control module (ECM), powertrain control module (PCM), etc. The vehicle fuel system needed to be in calibration for an extended service life, or provide a malfunction warning, and needed the inherent ability to incorporate programmable function limits, depending on vehicle platform and regulation year.[6] Quickly following the domestic introduction of EFI, electronic integrated circuit feedback controllers were introduced in stand-alone cruise control systems. A schematic of such a feedback system is shown in Fig. 1.2, where the controller is an ECU, the controlled parameter is throttle position (via vacuum or electromotor servos), and the feedback element is an electronic vehicle speed signal (VSS). The VSS is typically generated via a magnetic pulse generator sensing rotating gear teeth on the transmission output shaft. By the late 1980s, electromechanical feedback cruise control transducers (seen in production vehicles until 1983) were substantially obsolete. The next major area to be changed with electronic integrated circuit feedback controllers was braking systems. It was shown that, for poor road conditions (sand, ice, snow, water, etc.), a system that prevented wheel lockup and gave significantly increased directional control, in exchange for a small loss of absolute stopping distance, provided a major benefit to overall vehicle performance. This was accomplished by using an ECU to sense individual wheel speeds, and then isolate and reduce brake fluid pressure to the wheel or wheels that were locking up. A schematic of such a feedback system is shown in Fig. 1.3, where the controller is an ECU, the controlled parameter is wheel cylinder pressure (via electrical solenoid valves), and the feedback elements are individual electronic wheel speed signals (WSS). The WSS are typically generated via a pickup coil mounted adjacent to a toothed ring at each controlled wheel, where the pickup coil senses the magnetic flux changes as the teeth pass by.

Generally, starting with the 1990s era,[7] another new vehicle system needed to be in calibration for its service life, or provide a malfunction warning, and needed the inherent ability to incorporate programmable function limits, depending on vehicle platform. Passive restraints, specifically air bags and automatic seat belt tensioners, needed the capabilities inherent in ECU control. A schematic of a first generation air bag system is shown in Fig. 1.4, where an ECU serves as a diagnostic controller, and external inertia switches[8] at the front of the vehicle are used to sense the crash pulse and electrically deploy the air bag(s). This type of system inherently responds to a mechanical property (acceleration) to generate an electrical current to actuate a pyrotechnic device (electrically fired squib/gas generator which inflates a folded air cushion). Additionally, when a circuit problem is detected, the diagnostic controller (ECU) actuates a warning lamp to provide visual indication of a system malfunction to the operator.

Since this type of system was very complex and directly related to occupant safety, the ability to identify intermittent malfunctions was desired. Each malfunction is indicated by a numeric DTC (diagnostic trouble code). DTC storage was accomplished with special internal nonvolatile memory, which could record and store such past DTCs until a technician later read them. The readout process was accomplished via blink codes, where the SRS lamp was used as a blink counter to indicate the identification number of a stored DTC. Later, DTCs were also read out with special interrogating testers called *scan tools*, or more commonly, *scanners*. The scanner was itself another computer, which could access the nonvolatile memory in the air bag ECU. Additionally, the scanner could read DTCs and other stored information that could not be identified with blink codes.

A schematic of the scanner interrogation of an early-architecture air bag ECU is shown in Fig. 1.5. In this case, the scanner performs much like a palmtop computer which, when connected to a host computer, can read e-mail and stock prices. In this case, the scanner is plugged into a vehicle data port to read air bag ECU saved DTCs and saved parametric data. Modern scanners usually have their own EEPROMs, which save setup data on the last car serviced, thus giving the technician a shortcut to re-enter that vehicle's scanner operations.

Air bag ECUs perform a critical safety function, but they are hardly unique in architecture and construction. Thus, in a similar manner, ABS ECUs, powertrain ECUs, CC ECUs, etc., having similar architectures with internal EEPROM, could also be scanned for their DTCs and prior saved parametric data. Now that we have introduced the general functions of various vehicle system ECUs, it would be helpful to review the internal architecture of a generic ECU.

1.3 THE ARCHITECTURE OF AN ECU

In order to keep the text flowing smoothly, it is necessary to use many common industry acronyms in this section. These are fully defined in Appendix A. Readers unfamiliar with computer architecture and component jargon are encouraged to scan those sources before continuing.

The generic on-vehicle system ECU has many elements common to most other computer control units (desktop word processors, laptops, hotel accounting systems, microwave oven controllers, etc.). These common elements give it the inherent function to operate on a stored program and branch to alternate operations dependent on intermediate calculated results.

The core of an ECU is a common internal data path (data bus) that allows various data processing and data storage elements to exchange data efficiently. The internal data processing and data storage elements can include a CPU, RAM, PROM, EPROM, EEPROM, etc.

Additionally, outside of the data bus, there are usually interface circuits that condition or convert incoming signals, interface circuits that condition or convert signals from internal components, circuits that provide high power drive for

[6]This was done by using small "calibrator" modules tailored to the particular vehicle on which a generic electronic controller was applied.

[7]In actuality, GM equipped a small test portion of its fleet vehicles with air bags in the mid-1970s, and, in the mid- and late1980s, Ford and Mercedes-Benz had air bags in production vehicles.

[8]An inertia switch responds to change the state of its electrical contacts when it is subjected to an acceleration (crash) pulse to above its threshold. In SRS systems, when a crash-level pulse is detected, the contacts close. Other versions of inertia switches are used to open electric fuel pump circuits when an above-threshold acceleration (crash) pulse is detected (First Inertia 1992).

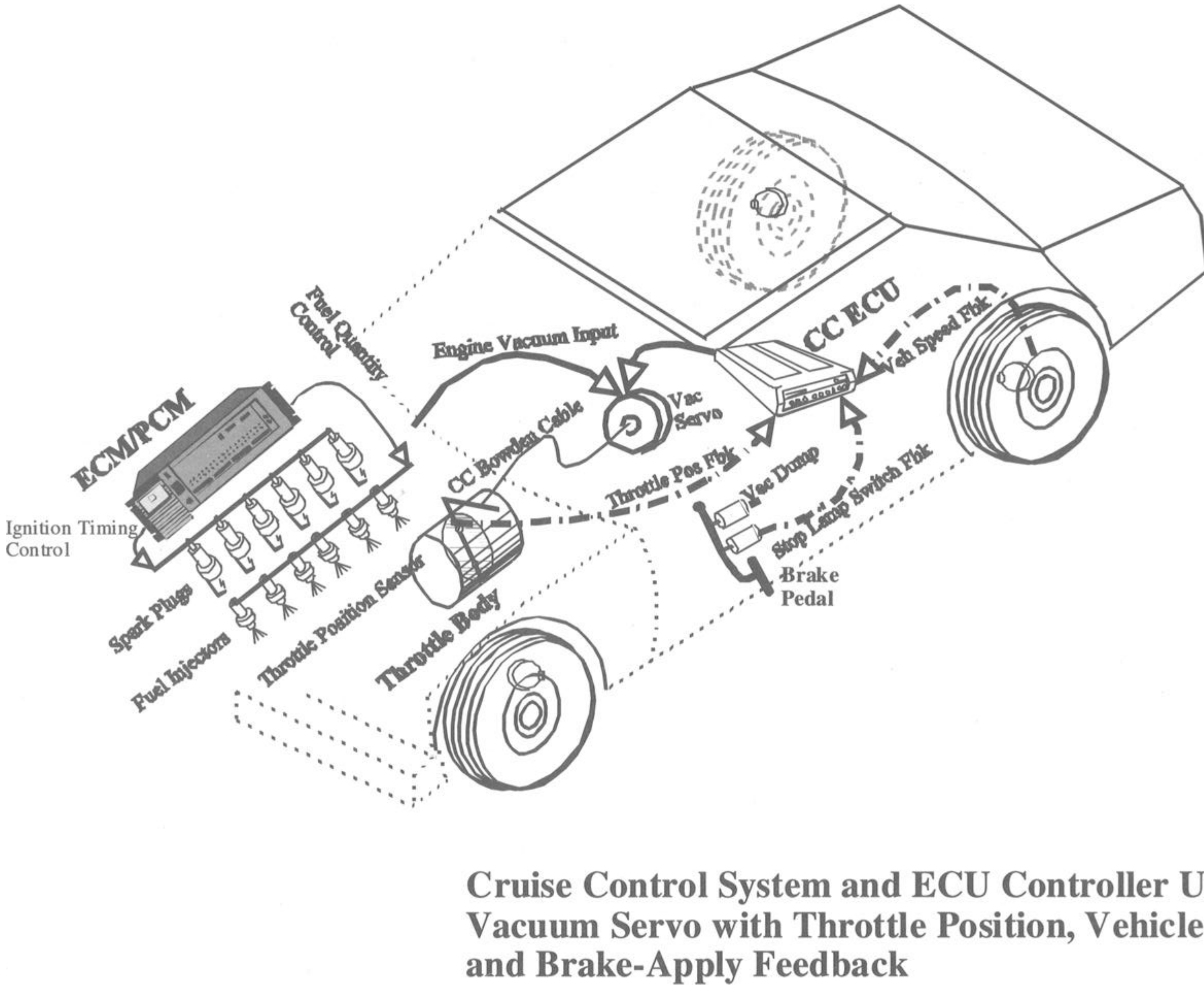


FIG. 1.2—ECU controlled cruise control system using vehicle speed feedback.

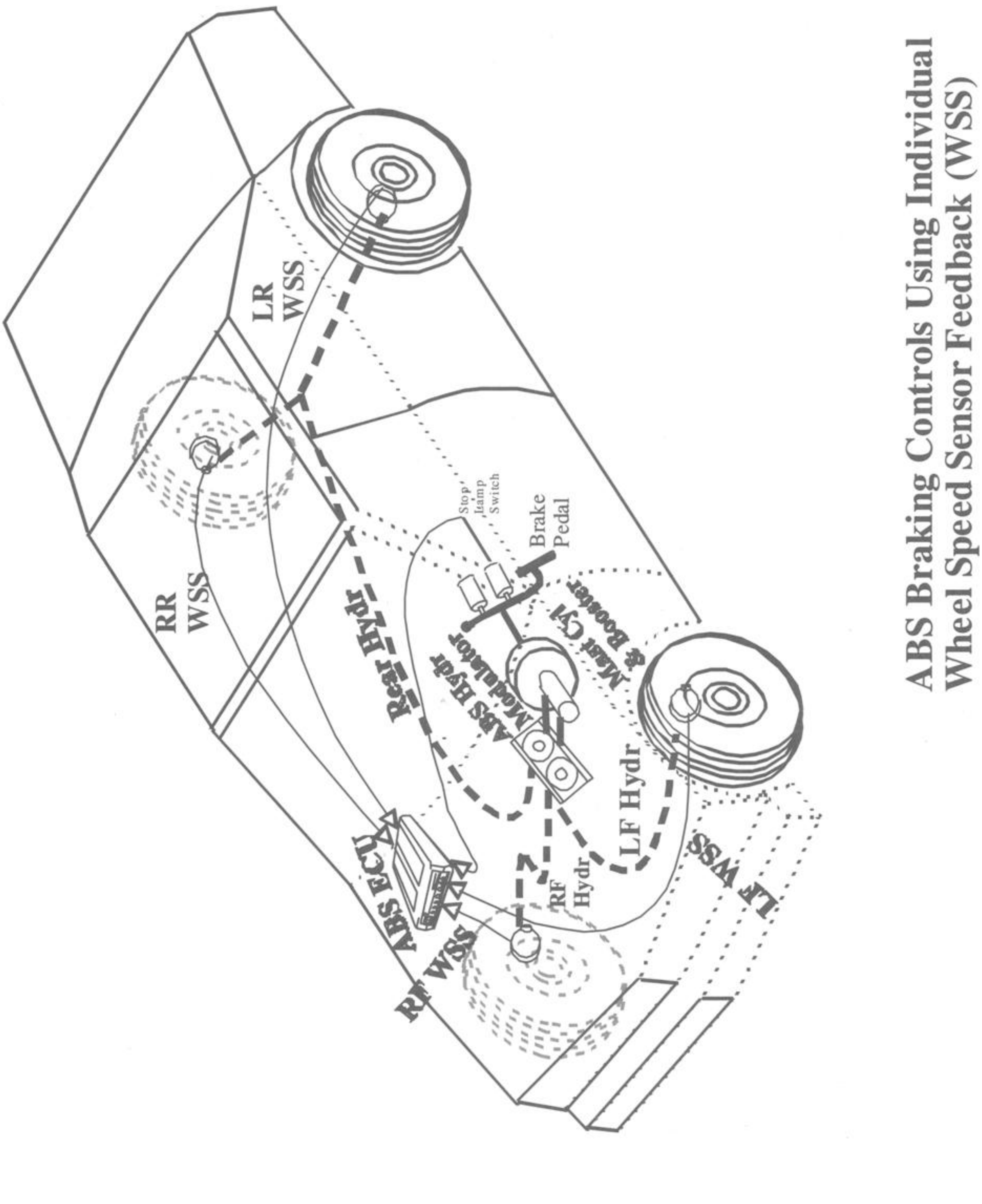


FIG. 1.3—ECU controlled ABS using individual wheel speed sensor feedback.

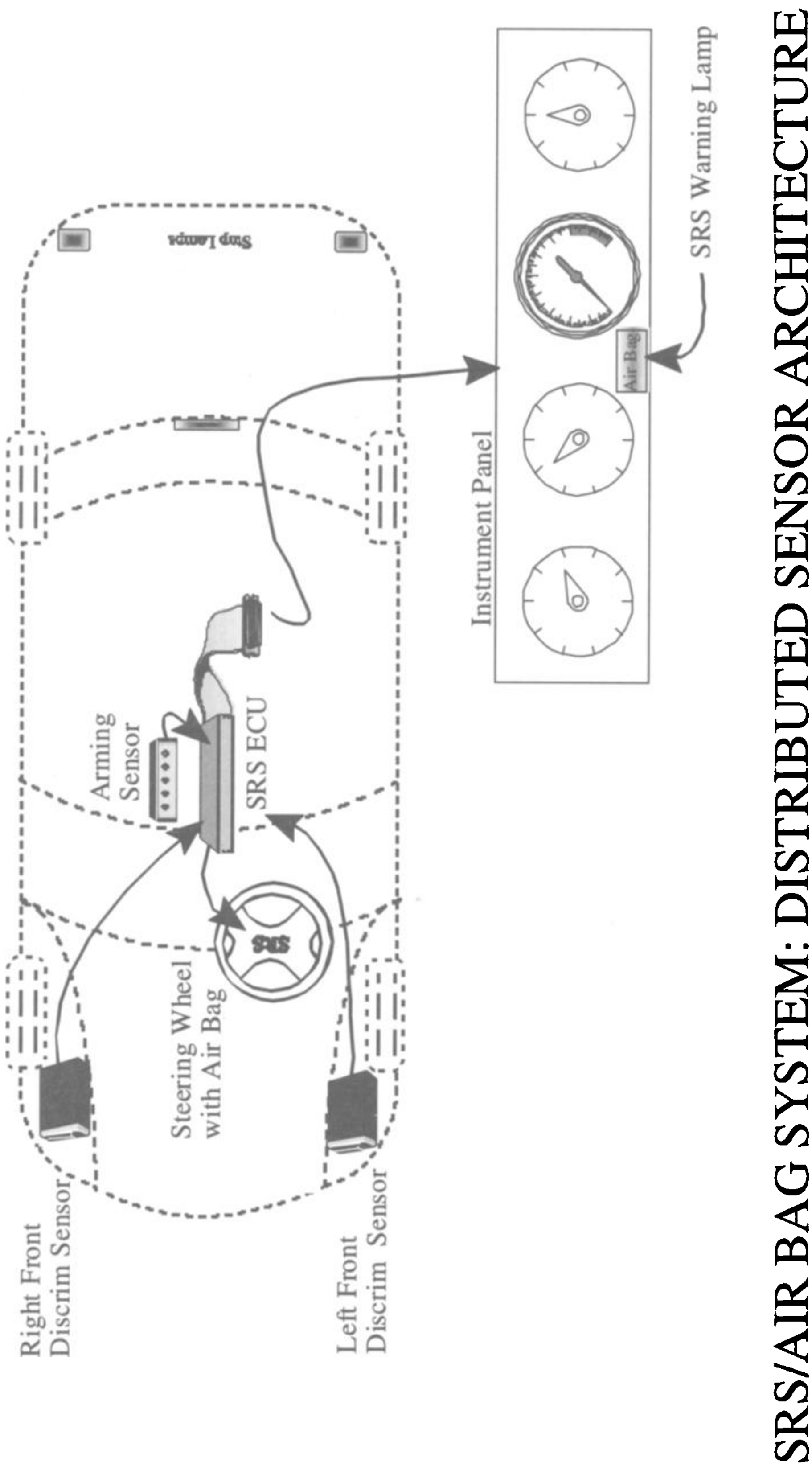


FIG. 1.4—Schematic of an early air bag system.

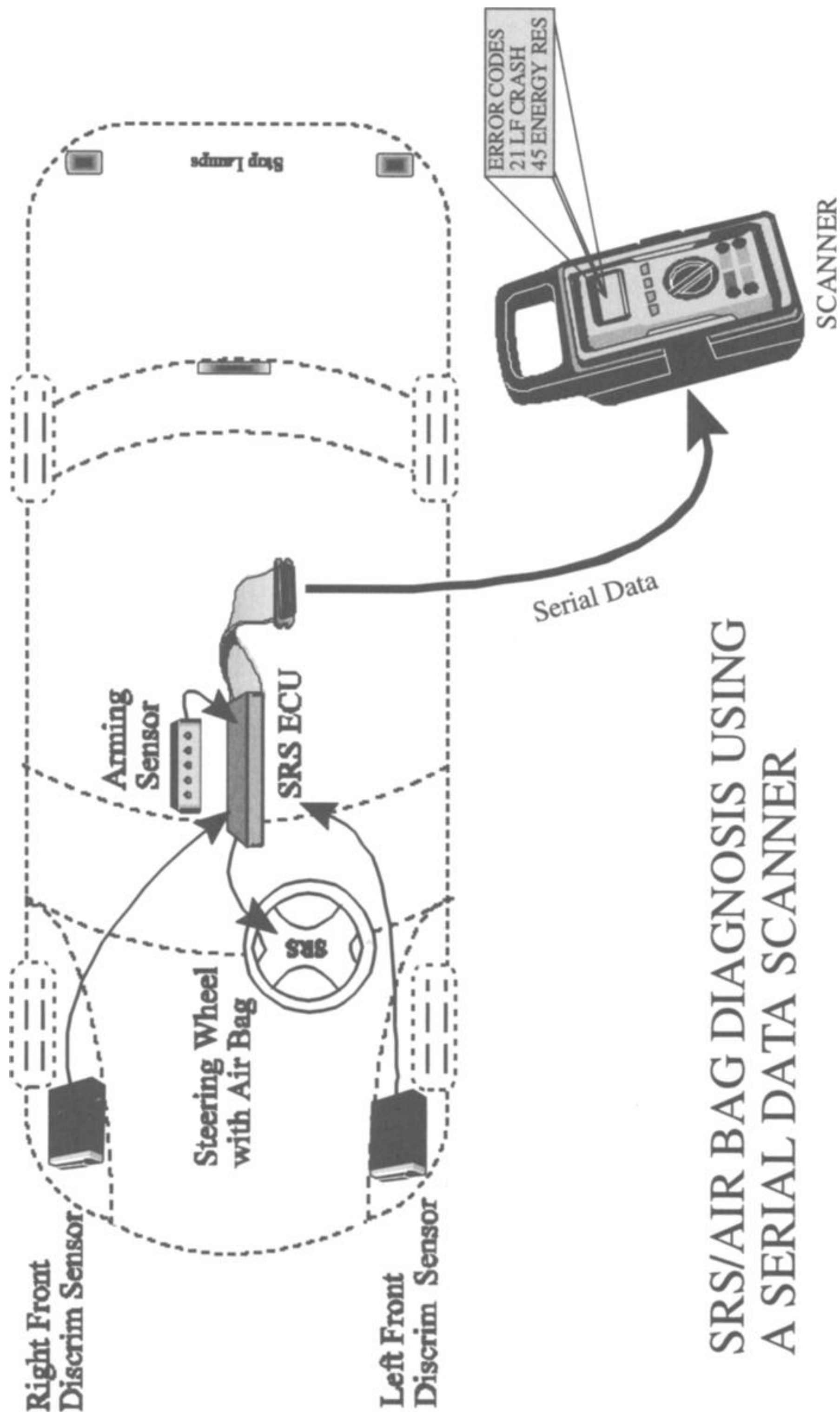


FIG. 1.5—SRS diagnostics using a scanner.

external actuators, and communication circuits that allow the ECU to pass data to other data devices (modems, networks, diagnostic scanners, etc.).

Figure 1.6 shows a composite tutorial ECU schematic containing illustrative elements that can be found in various SRS and ABS ECUs. The internal functions (RAM, CPU, PROM, etc.) could be implemented from separate integrated circuit devices and combined on a printed circuit board (PCB) to accomplish the ECU function, and many earlier devices were constructed that way. However, current technology permits a high degree of functional block integration, allowing the function of many of the memory and conditioning circuits to be incorporated in one device. One example of such a device is the Thomson TS 68HC811E2,[9] whose block diagram is shown in Fig. 1.7. Notice that 512 bytes of EEPROM are incorporated within the single controller version shown.[10] Such an integrated device is called a microprocessor unit (MPU), and using such an MPU inside an ECU greatly simplifies its design. However, this same MPU IC chip is sold in two package versions. Thus, if we are not privy to the design data for this MPU (which contains the EEPROM in our ECU), we may have to use the MPU packaging definition to queue our research for the particular specification that may define just how many bytes of EEPROM data are stored in the MPU device, and hence in the ECU. For the TS 68HC811E2 MPU, the packaging options are shown in Fig. 1.8. This concept will be important to remember later, when we attempt to characterize an unknown ECU by finding out what the nonvolatile data capacity actually is, and how it may be accessed.

1.4 VEHICLE ENVIRONMENTS WITH MULTIPLE SYSTEM ECUS

As discussed above, contemporary passenger vehicles typically incorporate ECUs as the control element in systems including engine fuel management (EFI), antilock braking (ABS), automatic traction control (ATC), cruise control (CC), air bags (SRS), seat belt tensioners (ETR), suspension control (RSS), and occupant options (seat adjustment, steer wheel adjustment, etc.).

In the earliest generations of these systems, individual functions were usually independent of other systems, with separate sensors and separate actuators. Shortly thereafter, the first steps in system integration incorporated common sensors for similar functional inputs (VSS for vehicle speed, ignition-primary for tachometer, stoplamp circuit for brake apply, etc.). The next steps involved cross system communication and control functions to achieve more sophisticated vehicle control than stand alone systems could achieve. An example of this communication link, shown in Fig. 1.9, is a coupling of antilock brake control and engine power management to achieve an automatic traction control (ATC) function for optimum vehicle acceleration and tracking.

Once more than two ECUs became involved in a communication link, it became immediately obvious that a more cohesive system of communications was required. This cohesive system has evolved as a network of ECUs with an extensive set of layered protocols, message formats, and physical interconnections defined by an umbrella of standards. This network of ECUs is formally called a controller area network (CAN) and is also defined as an SAE J1850 network (Bosch 1991; SAE 1998). These networks are characterized by an open system architecture (OSI)[11] and a well-documented set of definitions and specifications,[12] which makes their application universal. Many of these vehicle systems standards are listed in Appendix D, which includes entries from the International Standards Organization (ISO) and the Society of Automotive Engineers (SAE). Regulations to which these standards respond are listed in Appendix C, which includes entries from the California Air Resources Board (CARB) and the Environmental Protection Agency (EPA).

A conceptual schematic of the physical circuit of such a vehicle controller network is shown in Fig. 1.10. In this figure, the vehicle network is seen as a common serial communications circuit, connecting all communicating ECUs. Inter-ECU communications are sent as serial data on this common path, with an established system of protocols, identities, and formats. The common electrical circuit is known as the physical/electrical network, and this is specified in Layer 3 of the ISO CAN specification structure. These three layers are defined in Table 1.4. One very complete ISO CAN specification, obtainable via the internet, is Bosch CAN Specification 2.0 (see Appendix D).

The SAE implementation of CAN concepts is embodied in an umbrella of specifications dealing with the SAE J1850 Class B Data Communications Network Interface (see Appendix D). Figure 1 of SAE J1850, presents a convenient map relating ISO CAN versus SAE J1850 nomenclature and function by protocol layer and is reproduced here as Fig. 1.11.[11] Using the layered message disciplines and protocols, CAN/SAE J1850 supports distributed (separate) real time ECU systems controllers with a high degree of data integrity.

One principal advantage of vehicle networks is that they efficiently multiplex inter-ECU communications over a few wires at high bit rates. They also allow different systems to share sensors, thus saving weight, space, and vehicle diagnostic complexity. Besides saving the weight and complexity of system stand-alone vehicle wiring harnesses, networking methodology simplifies and standardizes advanced system integration functions. Aside from the ATC example discussed above, networking methodology is used to implement advanced inter-ECU functions such as speed-sensitive door locks, advanced instrument panel data, smart air bags, smart electric windows, collision sensing, smart seat belts, etc.

In general, any ECU has equal access to the vehicle bus. Additionally, units can be connected or unconnected at will, without affecting the bus or message integrity. Extending

[9]Derived from the Motorola 68HC11 family.

[10]Although 2K bytes of EEPROM are available in other versions.

[11]OSI is defined as a publicly available interface definition, which allows independent designers and manufacturers to share a common interface format.

[12]Examples of open protocols and interconnections standards are found in standard computer systems parallel/printer peripheral ports. Recall that just about every manufacturer's printer, new and old, uses the "Centronics" port definition and a standard "Centronics" printer cable (updated to IEEE1284 for bidirectional communications).

[13]Used with permission of the SAE.

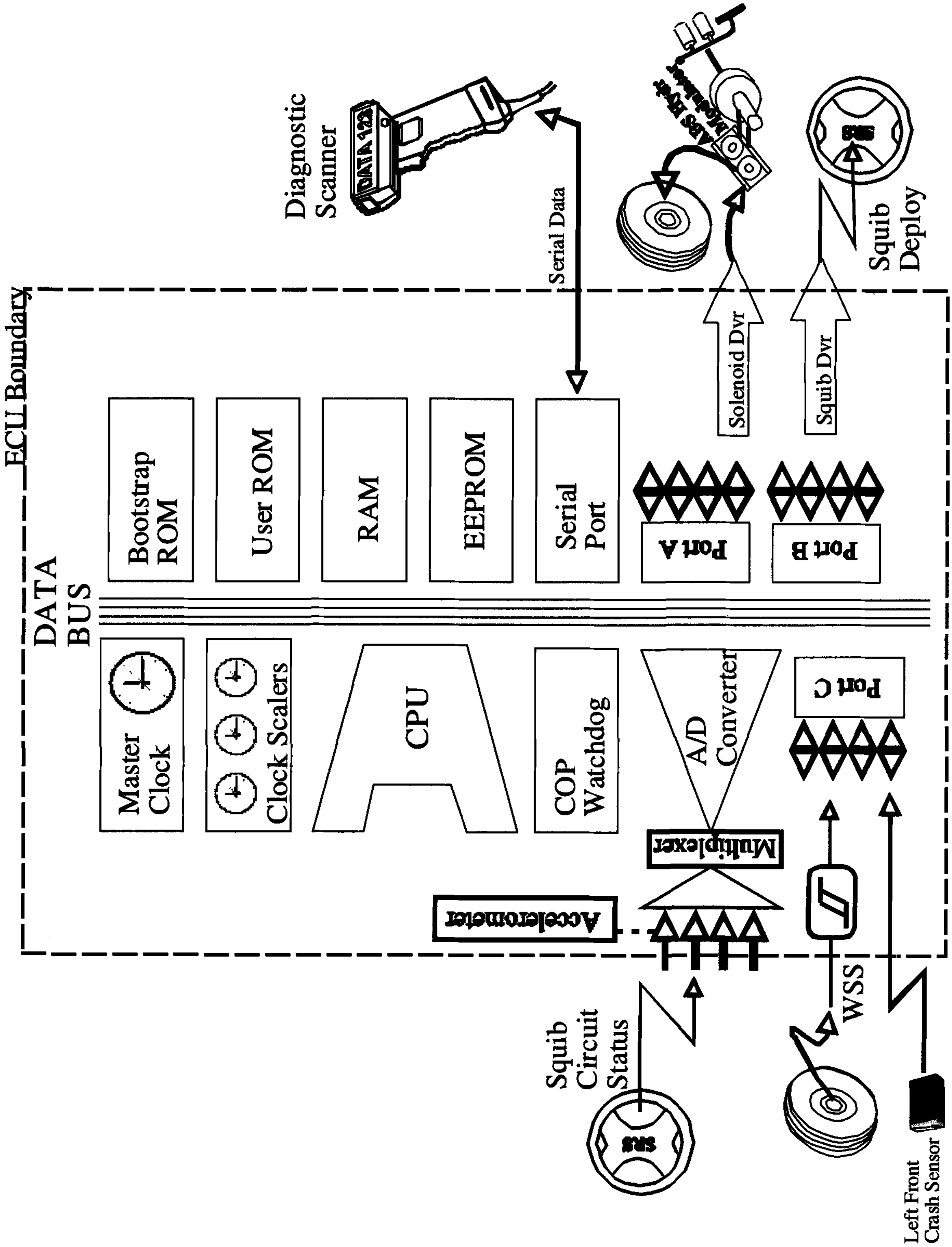


FIG. 1.6—Composite tutorial ECU architecture.

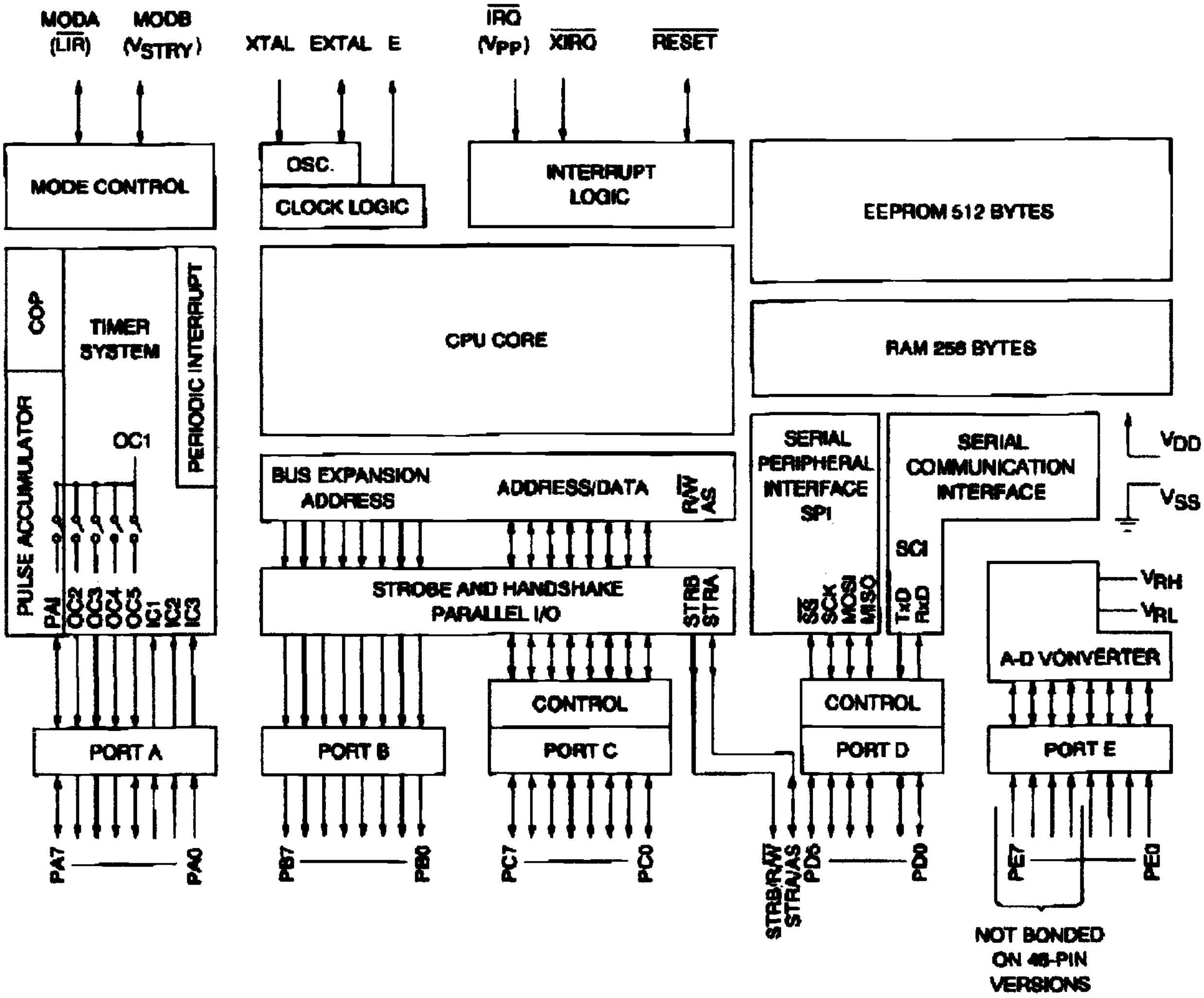


FIG. 1.7—Thomson TS 68HC811E2 MPU. (Courtesy of Thompson-CSF Semiconducteurs Specifiques.)

that concept, one can see how a diagnostic scanner can connect to the bus, and, with proper protocols, query one or more vehicle ECU for the data it contains. This implementation of a diagnostic tool (ECU) in a networked environment is shown in Fig. 1.12, which adds a diagnostic ECU to the network of Fig. 1.10.[14]

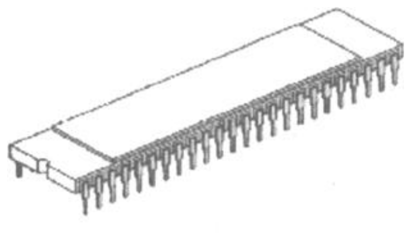
1.5 ON-BOARD DIAGNOSTICS—II (OBD-II)

The connection of a diagnostic ECU to an on-vehicle network is a routine operation in today's vehicle service environment. With a CAN/SAE J1850 approach, a diagnostic tool can be considered as just another ECU added to the network. Since those diagnostic ECUs are generally portable and have the capability to poll (scan) various on-vehicle ECUs for DTCs and parametric data, they are called *scan tools*, or more commonly, *scanners*.

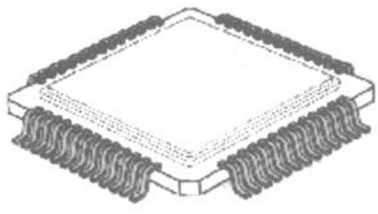
As explained above, on-board diagnostic communications access has evolved dramatically in the 1990s from its beginnings in the late 1950s and early 1960s. At this time, the atmospheric smog problem in the Los Angeles basin was becoming legendary and intolerable. To combat this smog problem, the state of California started requiring emission control systems on 1966 model cars. The federal government extended these controls to nationwide application in 1968. In 1970, Congress passed the Clean Air Act and established the Environmental Protection Agency. The EPA initiated a series of graduated emission standards and requirements for maintenance of vehicles. These were to become more stringent with passing years (EPA 1998). Many of these are listed in Appendix C.

It was unclear that all-mechanical systems, without feedback, could meet the durability requirement of these increasingly stringent standards without costly maintenance (e.g., frequent tune-ups). So, manufacturers turned to electroni-

[14]This is also very clearly explained in SAE J 1939-81, Section 3.3.2.



C Suffix
DIL 48
Ceramic side brazed dual in line



F Suffix
CQFP 52
Ceramic quad flat pack

FIG. 1.8—Packing options for Thomson TS 68HC811E2 MPU. (Courtesy of Thompson-CSF Semiconducteurs Specifiques.)

cally controlled fuel feed and ignition systems with feedback regulation. Sensors were used to measure engine performance, and their readings were used as *feedback* to automatically adjust engine control systems to provide minimum pollution and optimum performance. These systems indicated any malfunctions by illuminating a lamp visible to the operator (malfunction indicator lamp, MIL). Various malfunction codes were also accessed electrically (using MIL blink codes) to provide diagnostic assistance.

In the beginning, manufacturers had their own systems, data formats, and diagnostic codes. Starting in the late 1980s, the Society of Automotive Engineers (SAE) began developing standards for diagnostic connectors and diagnostic test signals. The EPA adapted many facets of the SAE standards (see Appendix D), and OBD-II is the current, expanded set of standards and practices developed by SAE and adopted by the EPA and CARB. OBD-II implementation became mandatory on U.S. domestic vehicles by January 1, 1996. Thus, today's scanners universally connect to the CAN/SAE J1850 OBD-II on-vehicle network port.

There are four basic OBD-II communication protocols in use, each with minor variations on the communication pattern between the on-board diagnostic computer. These are generally grouped as follows:

- ISO 9141-2/ISODIS (K Line = 10.4 Kbps bi-directional, L Line = 5 bps, Scanner-to-ECU Communication)
- SAE J1850 VPW (10.4 Kbps variable pulse width modulation)
- SAE J1850 PWM (41.6 Kbps pulse width modulation)
- SAE J2284 (500 Kbps high speed CAN-HSC)

While there are several OBD-II compliant electrical communication protocols, the mandatory field data formats and structures are fixed according to SAE J1979 and SAE J2178, and any new vehicle system (and hence new scanners) must be compatible with these formats and structures.

Additional to message formats, structures, and priorities, the physical interconnection to the on-vehicle network is designated to be a standard "OBD-II" connector. The physical SAE J1962 OBD-II connector layout is shown in Fig. 1.13. This connector is seen in all compliant vehicles starting in 1996.

There is no limit on design variations of scanners (Diagnostic ECUs) that can comply with the ISO9141/SAE J1850/SAE J1979/SAE J2178 specifications, but they must all physically connect to the same SAE J1962 connector, must report the same standard (mandatory field) data, and must all automatically determine which communication protocol is being used. The concept of multiple scanner types connecting to a common SAE J1962 OBD-II network interface port is shown in Fig. 1.14.

OBD-II data consists of two parts, both acquired from the vehicle network by a serial access protocol. The first part is legislated, and it is often referred to simply as OBD-II (Onboard Diagnostics, Version II). The OBD-II functions are made available to all service technicians, and allow scanners to interrogate any ECU on the network for defined information accessible by service technicians. All ISO9141/SAE J1850/SAE J1979/SAE J2178 compliant OBD-II equipped vehicles, 1996 and later, including all European, Asian, and domestic products built for North America and Japan, have the following basic ODB-II diagnostic modes (SAE 1997):

Mode 1: *Request Current Powertrain Diagnostic Data*
This mode allows access to real time emission-related data values, including analog inputs/outputs, digital inputs/outputs, calculated values, and system status. The formats of the parameters included here are defined by SAE J2178.

Mode 2: *Request Powertrain Freeze Frame Data*
This mode allows access to emission-related data values, including analog inputs/outputs, digital inputs/outputs, and system status that were stored during the freeze frame required by OBD regulations. The formats of the parameters included are defined by SAE J2178.

Mode 3: *Request Emission-Related Powertrain Diagnostic Trouble Codes (DTCs)*
This mode allows the diagnostic test unit (scan tool or scanner) to access stored emission-related DTCs. This is a two-step process. Step 1 consists of a Mode 1 request to all ECUs to get the number of emission-related codes stored by the respective ECUs. Step 2 consists of the actual request for emission-related DTCs from the respective ECUs. The scanner reads the DTCs directly from the target ECU memory and displays a short description of each code. The DTC coding is defined by SAE J2012. When no DTCs are found, the scanner screen displays No Fault(s) Stored.

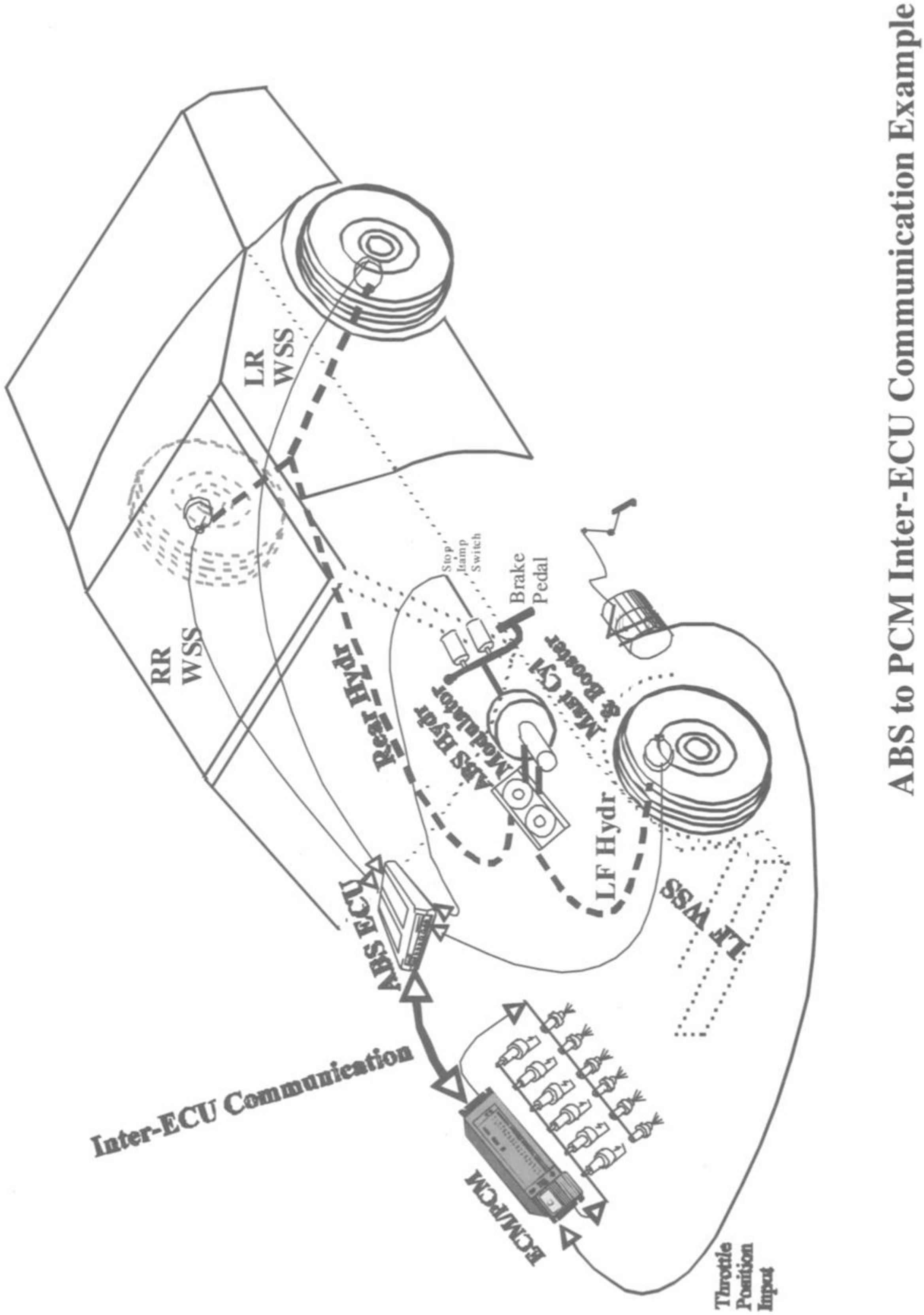


FIG. 1.9—Inter-ECU communication example, engine ECU to/from ABS ECU.

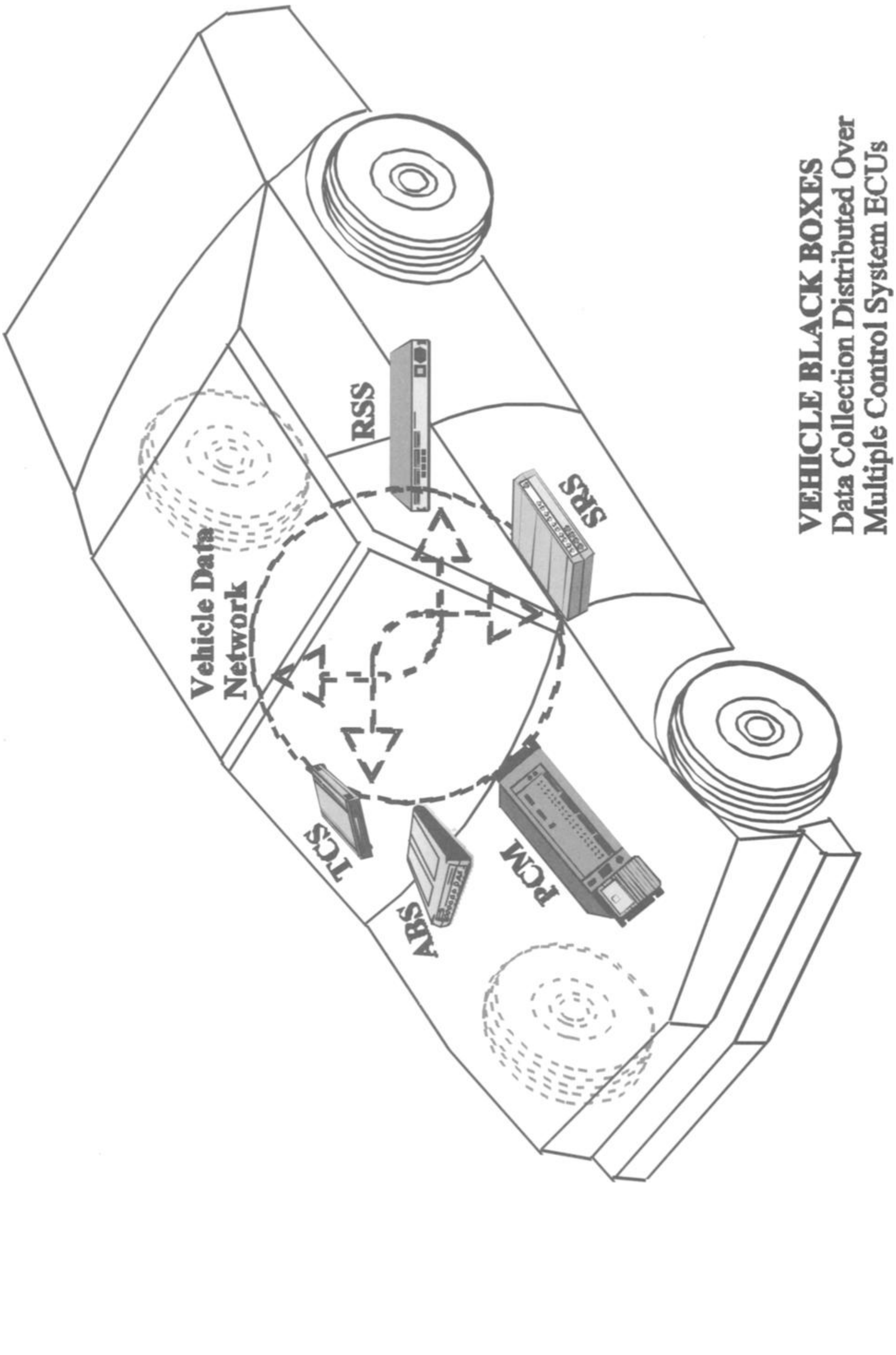


FIG. 1.10—Vehicle network, simplified schematic.

TABLE 1.4—ISO Controller Area Network (CAN), layer hierarchy specification.

Layer	Title and Description
1	*Application/Object Layer*—specifies standard message codes, standard parameters, message filtering, status and routing.
2	*Data Link/Transfer Layer*—specifies message timing, synchronization, framing, priority-arbitration, and error detection.
3	*Physical & Electrical Inter-ECU Communication*—specifies wiring type, connectors, and transmission characteristics.

Mode 4: *Clear/Reset Emission-Related Diagnostic Information*
This mode allows the diagnostic test unit (scan tool or scanner) to clear all emission related diagnostic information. This includes clearing or resetting the following information: Number of DTCs (Mode 1, PID 01); DTCs (Mode 3); DTC freeze frame data (Mode 1, PID 02); Freeze frame data (Mode 2); Oxygen sensor test data (Mode 5); System monitoring test status (Mode 1, PID 01); Other manufacturer-specific data.

Mode 5: *Request Oxygen Sensor Monitoring Test Results*
This mode allows the diagnostic test unit (scan tool or scanner) to access on-board oxygen sensor test results. There are many ways to comply with this requirement, and use of this mode may be optional depending on manufacturer compliance approach.

Mode 6: *Request On-board Monitoring Test Results for Noncontinuously Monitored Systems*
This mode allows the diagnostic test unit (scan tool or scanner) to access on-board test results for systems and components that are not continuously monitored, such as catalytic converters and evaporative canisters.

Mode 7: *Request On-board Monitoring Test Results for Continuously Monitored Systems*
This mode allows the diagnostic test unit (scan tool or scanner) to access on-board test results for systems and components that are continuously monitored. This mode is useful when the repair technician wishes to ascertain malfunctions occurring immediately after clearing all DTCs and before a next DTC is set (where they would be reported in Mode 3).

Mode 8: *Request Control of On-board System, Test, or Component*
This mode allows the diagnostic test unit (scan tool or scanner) to control the operation of an on-board system test or component. Such control can include: Turn device off, Turn device on, and Cycle device for x number of seconds. This mode can then be used to determine specific system/component response to individualized tests.

Mode 9: *Request Vehicle Information*
This mode allows the diagnostic test unit (scan tool or scanner) to request vehicle-specific information such as VIN, Calibration IDs, ECU Ids, and control software levels.

Table 1.5.1 identifies the mandated and optional signal connections in the OBD-II connector by which the vehicle network is accessed. More detail of the specific bit rates, interface logic and conversion circuits can be found in SAE J2201, Interface for OBD-II Scan, June 93.

The second part of OBD-II accessible information is designated as special data that is generally proprietary to the vehicle manufacturer. These special data include functions such as reprogramming EEPROM or flash memory, reading and clearing advanced diagnostic codes, and accessing certain parametric and history information. Interrogation of this special data often requires different scanners,[15] and interpretation of this data often requires a knowledge of the data formats used in the proprietary data section in the target ECU EEPROM or flash memory. These proprietary data often contain information to assist with engineering analysis of the performance of current on-board systems and information to aid in the development of future systems. It is generally this special data, containing performance records in on-board EFI, ABS, ATC, CC, SRS, and ETR systems, colloquially identified as vehicle black box data, that is useful in crash analysis. Table 1.5.2 shows examples of manufacturer-variations in signals ported to the standard OBD-II connector.

1.6 FREEZE FRAME DATA THAT IS USEFUL FOR CRASH ANALYSIS

SAE J1978 and SAE J1979 specify freeze frame data capabilities required in the OBD-II environment. Freeze frame data are saved when a specific (SAE J2012 coded) DTC is detected and saved.

Table 1.6.1 shows the SAE J2012 DTC assignments and associated common system identifications. Each DTC consists of an alpha-numeric designator followed by three digits. In cases where the information is unclear, the binary upper-nibble identifier is used as a specific identifier. A more mnemonic view of DTC identification is shown in Fig. 1.15. However, since the principal objective of the diagnostic requirements was control of polluting emissions (and maintenance of drivetrain systems), most of these DTCs are not designed to provide crash data related information. A small subset of DTCs, mostly outside the emissions DTCs, can be useful in crash investigations.

Examples of vehicle information and DTC freeze frame parameters that can be useful in crash investigations are shown in Table 1.6.2. These, and other event-triggered parameters, will be further discussed in Chapters 5, 6, and 7. It may also be instructive to review Appendix E. After reviewing Tables 1.6.1, 1.6.2, and Appendix E, the advanced reader

[15]Or a different scanner program PROM which can contain a special serial protocol.

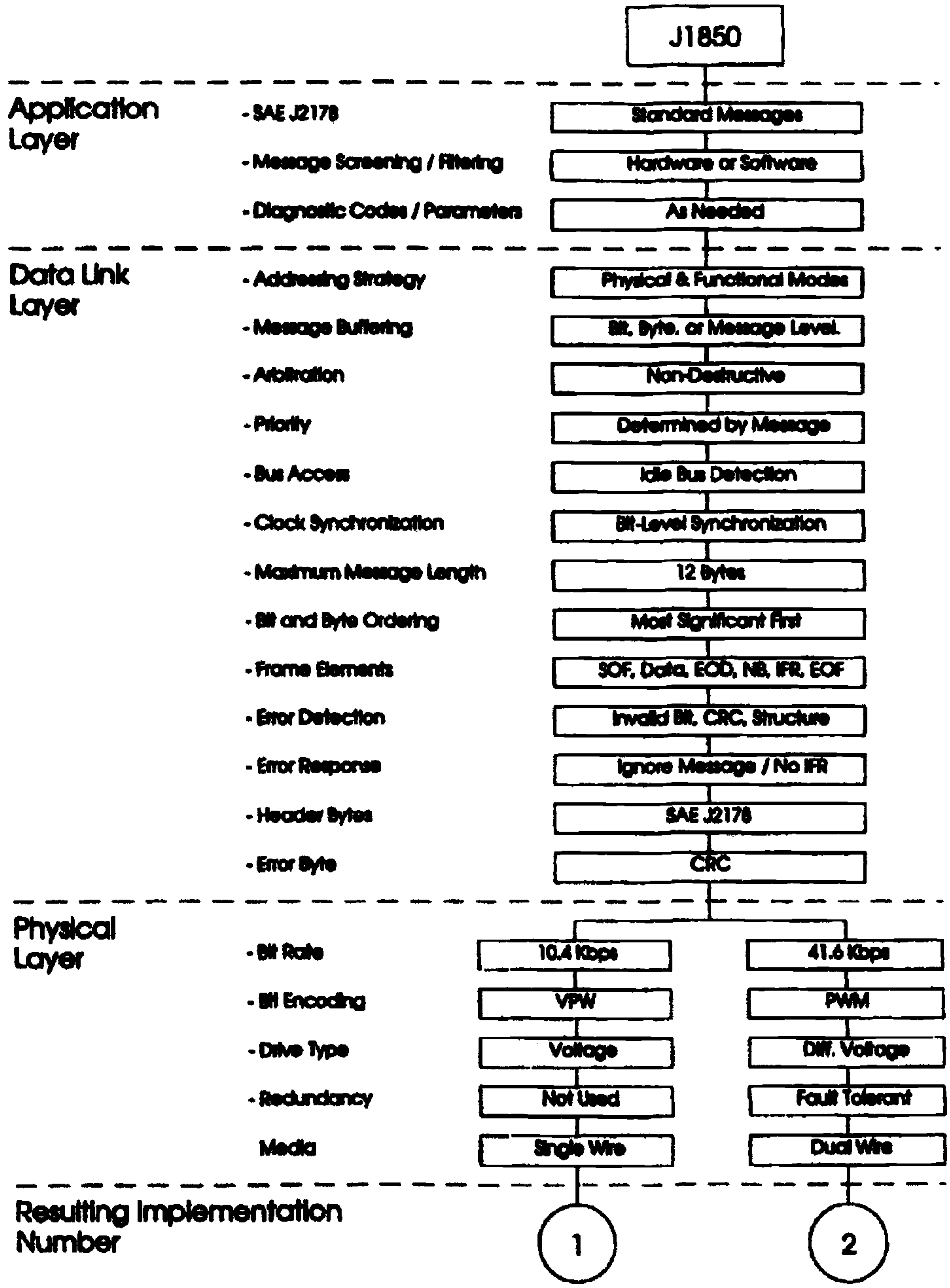


FIG. 1.11—Map of vehicle CAN protocol layers, ISO OSI vs. SAEJ1850. (Reprinted with permission from SAE document J1850,® March 1998, Society of Automotive Engineers, Inc.)

can skip to Chapters 5, 6, and 7 to plunge directly into the heart of finding and using on-vehicle stored crash-related parameters for crash scenario analysis. However, for those not familiar with this field, and as a refresher for those who are, several foundational chapters are included before Chapter 5:

- Chapter 2: Geometric Conventions, The Physical Laws of Motion, Acceleration Models and Numbering Systems
- Chapter 3: A Review of Air Bag System Architecture, Components, and Stored Data
- Chapter 4: A Review of Antilock Braking System Architecture, Components, and Stored Data

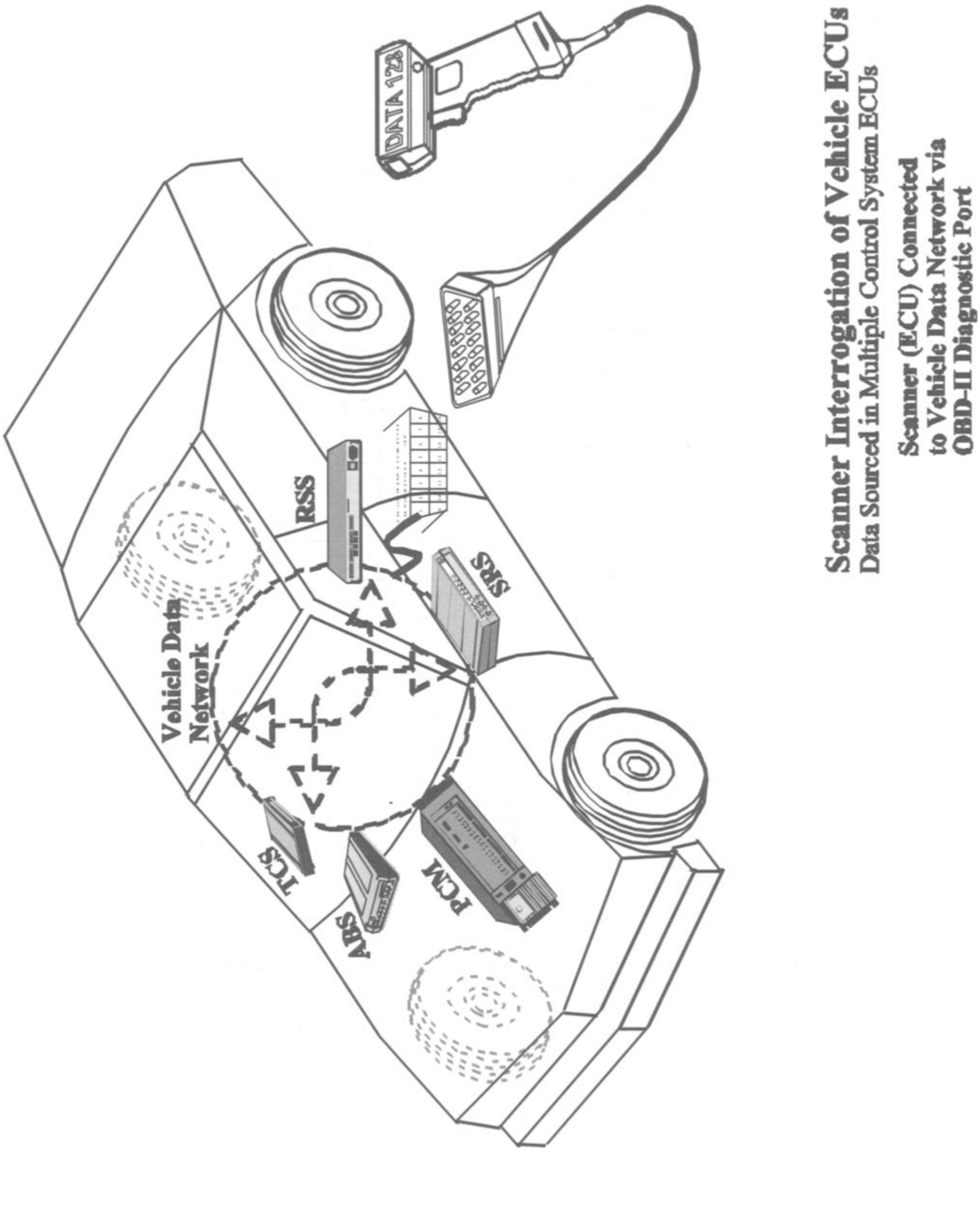


FIG. 1.12—Vehicle network with diagnostic scanner attached.

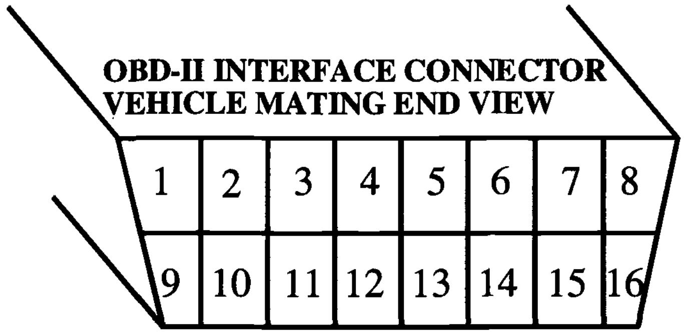


FIG. 1.13—In-vehicle mating end face of OBD-II connector showing pin number assignments.

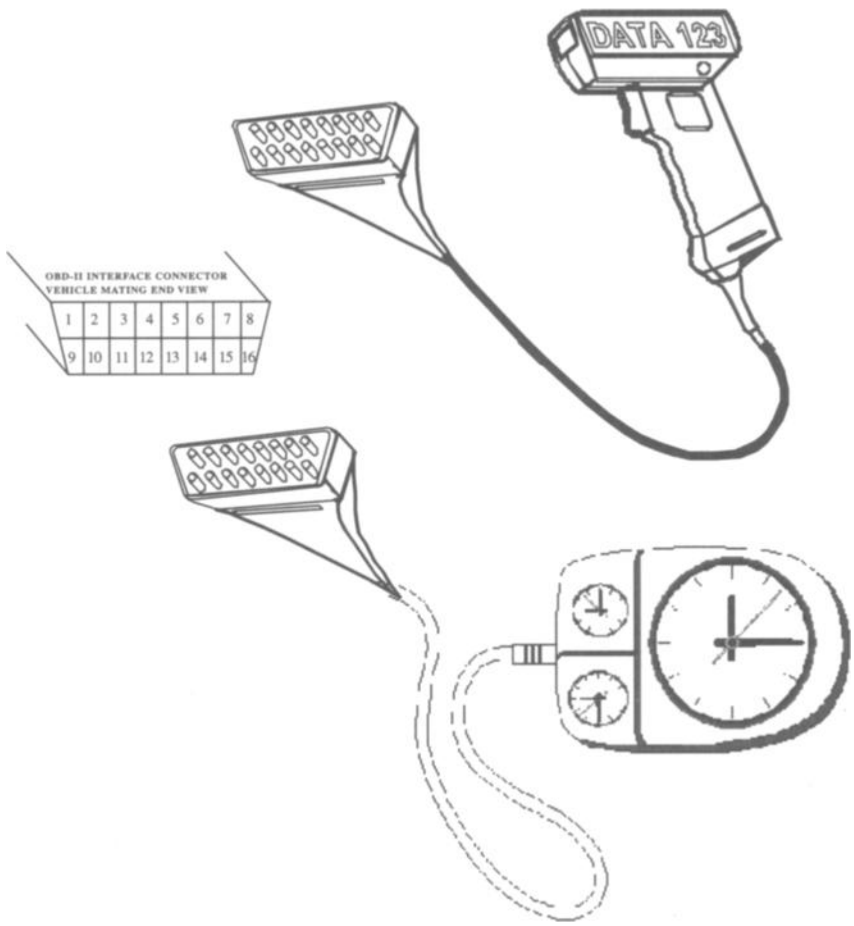
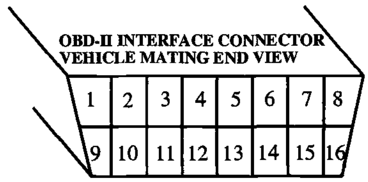


FIG. 1.14—Common scanner connection, different scanner design.

TABLE 1.5.1—Mandated and optional signal connections in the OBD-II Connector.



Pin #	OBD-II Connector Function
1	Manufacturer Discretionary
2	SAE J1850, (10.4 Kbps VPW Single Line or 41.6 Kbps PWM Bus +)
3	Manufacturer Discretionary
4	Chassis Ground
5	Signal Ground
6	SAE J2284, 500 Kbps High Speed CAN - HSC, CAN_High
7	ISO 9141-2/ISO-DIS 14230-4, K Line (10.4 Kbps bidirectional)
8	Manufacturer Discretionary
9	Manufacturer Discretionary
10	SAE J1850, 41.6 Kbps PWM (Bus-)
11	Manufacturer Discretionary
12	Manufacturer Discretionary
13	Manufacturer Discretionary
14	SAE J2284, 500 Kbps High Speed CAN - HSC, CAN_Low
15	ISO 9141-2/ISODIS 14230-4, L Line (5 bps, Scanner to ECU communication, Initial phase only)
16	Unswitched Vehicle Battery+ (4A max)

TABLE 1.5.2—Examples of manufacturer-variations in signals ported to the standard OBD-II Connector.

Pin #	OBD-II Connector, Manufacturer Discretionary Functions (Varies by Model Year)		
	Chrysler	Ford	GM
1	Remote Keyless Entry	Ignition Control	
2	SAE J1850, (10.4 Kbps VPW Single Line-or-41.6 Kbps PWM Bus +)	SCP Bus +	SAE J1850, (10.4 Kbps VPW Single Line-or-41.6 Kbps PWM Bus +), (Class 2)
3	CCD Bus +		Diagnostic Enable Signal—Ride Control
4	Chassis Ground	Chassis Ground	Chassis Ground
5	Signal Ground	Signal Ground	Signal Ground
6	SCI Engine Flash, Rx	Class C Link Bus +	
7	ISO 9141-2/ISO-DIS 14230-4, K Line (10.4 Kbps bidirectional)	ISO 9141-2/ISO-DIS 14230-4, K Line (10.4 Kbps bidirectional)	ISO 9141-2/ISO-DIS 14230-4, K Line (10.4 Kbps bidirectional)
8	Ignition Key Switched Battery	Trigger Signal	Keyless Entry Program Enable Signal
9		Ignition Key Switched Battery	Primary UART, 8192 bps, (Class 1)
10	SAE J1850, (41.6 Kbps, PWM Bus -)	SCP Bus–	SAE J1850, (41.6 Kbps PWM Bus -)
11	CCD Bus–		Diagnostic—Ride Control, EVO/MSVA
12	Chassis Flash, Rx	Flash EEPROM Programming	ABS/CCM Diagnostics
13		Flash EEPROM Programming	SIR Diagnostic Enable
14	Transmission SCI, Rx	Class C Link Bus–	Entertainment and Comfort Bus
15	ISO 9141-2/ISODIS 14230-4, L Line (5 bps, Scanner to ECU Communication Initial Phase only)	ISO 9141-2/ISODIS 14230-4, L Line (5 bps, Scanner to ECU Communication Initial Phase only)	ISO 9141-2/ISODIS 14230-4, L Line (5 bps, Scanner to ECU Communication Initial Phase only)
16	Unswitched Battery + (4A max)	Unswitched Battery + (4A max)	Unswitched Battery + (4A max)

TABLE 1.6.1—SAE J2012 PID assignments and associated common system identifications.

Upper Nibble	Alpha ID	Vehicle Systems Designation	System ECU Association, Identification/Acronym
0000	P0	Powertrain Codes, SAE Controlled	PCM, ECM, ECA
0001	P1	Powertrain Codes, Manufacturer Controlled	
0010	P2	Powertrain Codes, Reserved	
0011	P3	Powertrain Codes, Reserved	
0100	C0	Chassis Codes, SAE Controlled	
0101	C1	Chassis Codes, Manufacturer Controlled	ABS, TCS, ATC
0110	C2	Chassis Codes, Manufacturer Controlled	
0111	C3	Chassis Codes, Reserved	
1000	B0	Body Codes, SAE Controlled	
1001	B1	Body Codes, Manufacturer Controlled	
1010	B2	Body Codes, Manufacturer Controlled	
1011	B3	Body Codes, Reserved	
1100	U0	Network Communication Codes, SAE Controlled	
1101	U1	Network Communication Codes, Manufacturer Controlled	
1110	U2	Network Communication Codes, Manufacturer Controlled	
1111	U3	Network Communication Codes, Reserved	

P0107

System Group	Control	Sub-System	Fault #
B: Body	0: SAE Controlled	1: Fuel and Air Metering	00 - 99
C: Chassis	1: Manufacturer Controlled	2: Fuel and Air Metering (injector circuit)	
P: Powertrain	2: Manufacturer/Reserved	3: Ignition Systems or Misfire	
U: Network	3: Reserved	4: Auxiliary Emissions Controls	
		5: Vehicle Speed, Idle Control, Auxiliary Inputs	
		6: Computer & Auxiliary Outputs	
		7: Transmission	
		8: Transmission	
		9: Reserved	
		0: Reserved	

The example shown is P0107, MAP Sensor Circuit Low, an Emissions-Related DTC from a 1996 Oldsmobile 98. This DTC is a *Type B* code, which is emissions related, sets and saves freeze frame data at the first occurrence, and illuminates the MIL on the second occurrence (usually in a second drive cycle).

DTC types are defined as follows:

A. *Type A* codes are emissions related, set and save freeze frame data on the first occurrence, and illuminate the MIL immediately.

B. *Type B* codes are emissions related, set and save freeze frame data on the first occurrence, and illuminate the MIL only on the second occurrence (usually in a second drive cycle).

C. *Type C* codes are not emissions related, set on the first occurrence, and illuminate the MIL. They may or may not save freeze frame data.

D. *Type D* codes are emissions related, set on the first occurrence, and do not illuminate the MIL. They may or may not save freeze frame data.

FIG. 1.15—Breakdown of a typical DTC (Diagnostic Trouble Code).

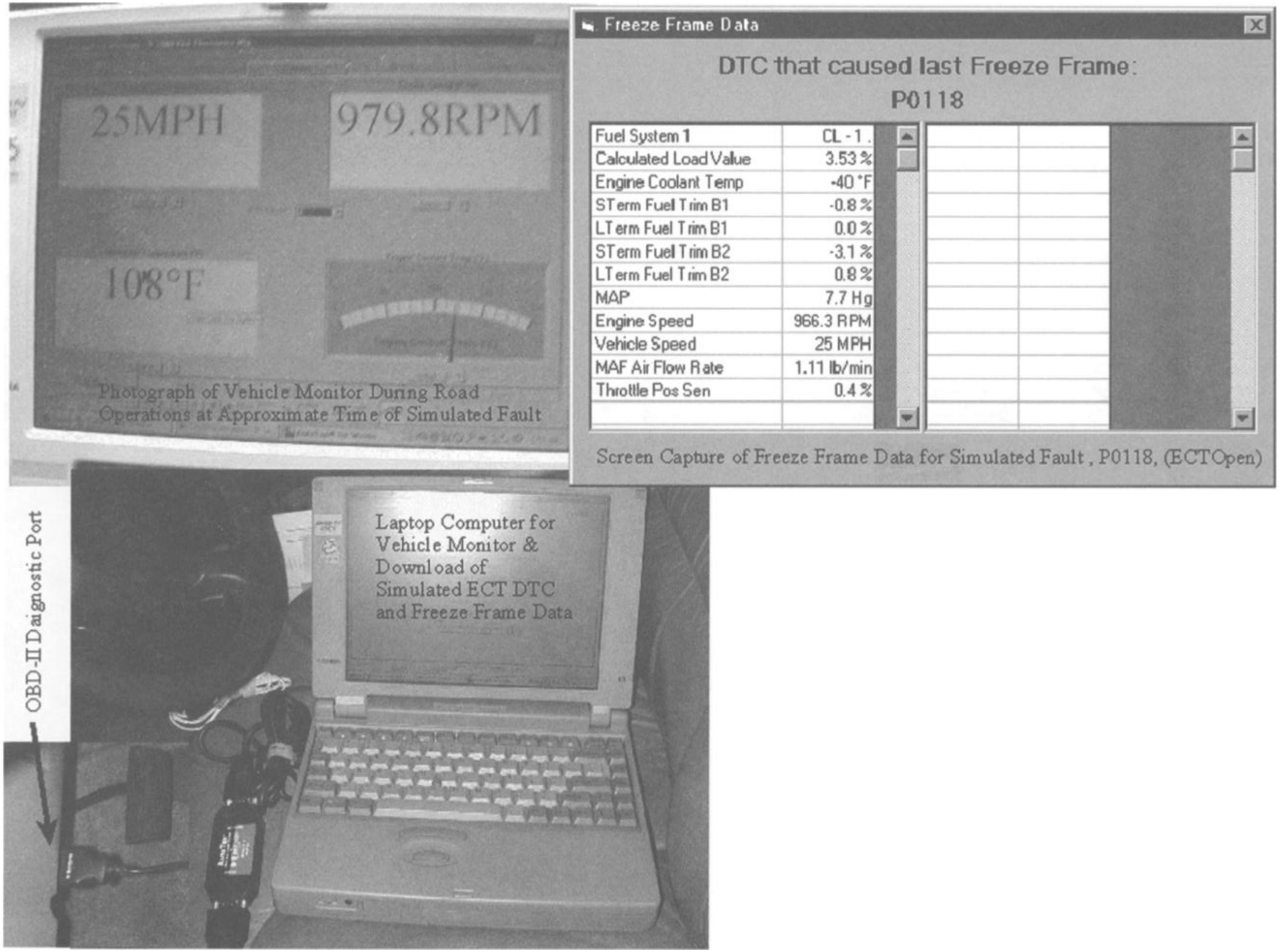


FIG. 1.16—Verification of a freeze frame parameter at 25 mph on a 1998 domestic model year truck with a simulated DTC. Data read using B&B Electronics AutoTap 12 with a laptop computer interface.

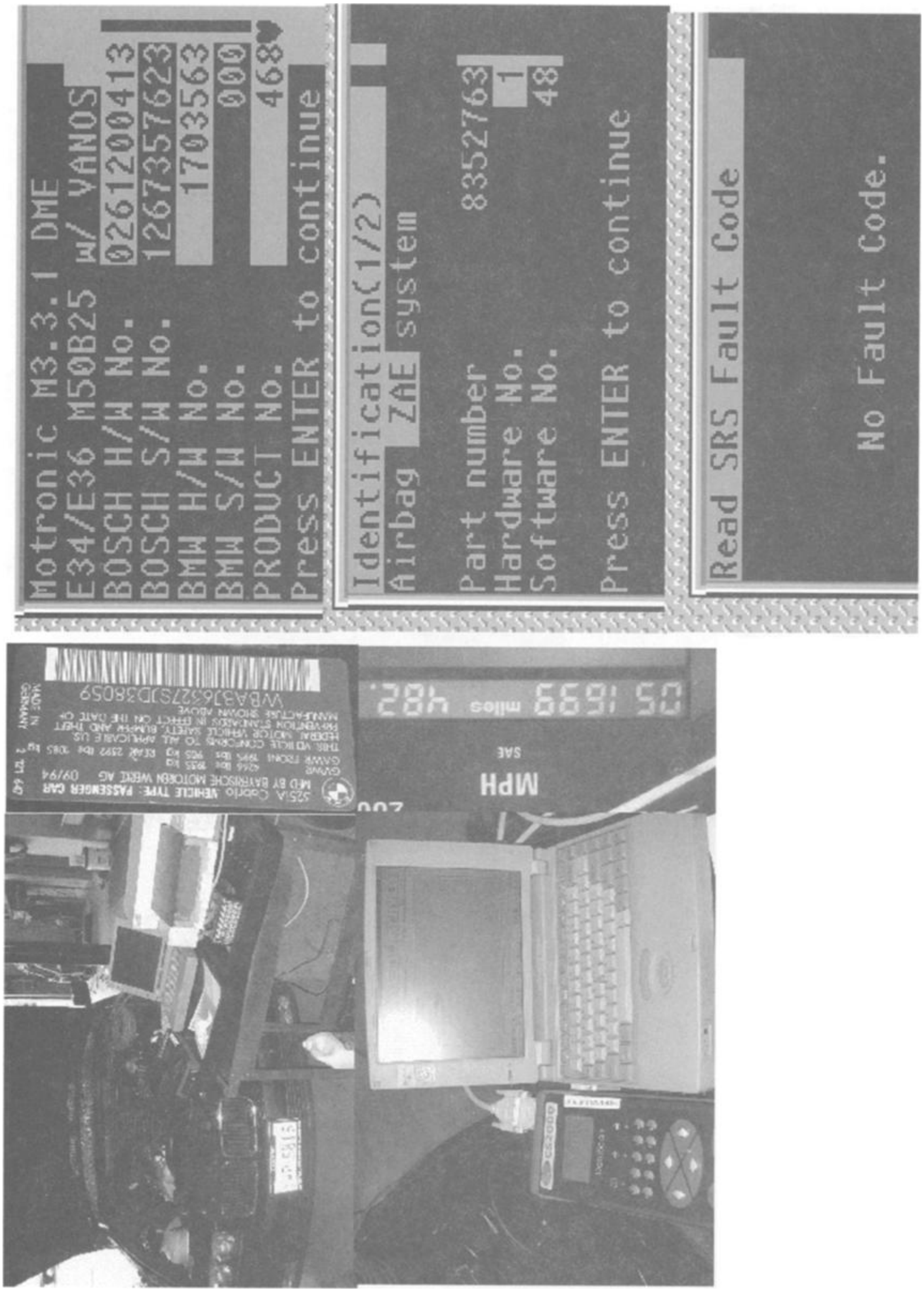


FIG. 1.17—Example data interrogation of a European 1995 model year vehicle showing PCM and SRS ECU part numbers with no DTCs stored in the SRS ECU. Data read using a BAUM CS2000 scanner.

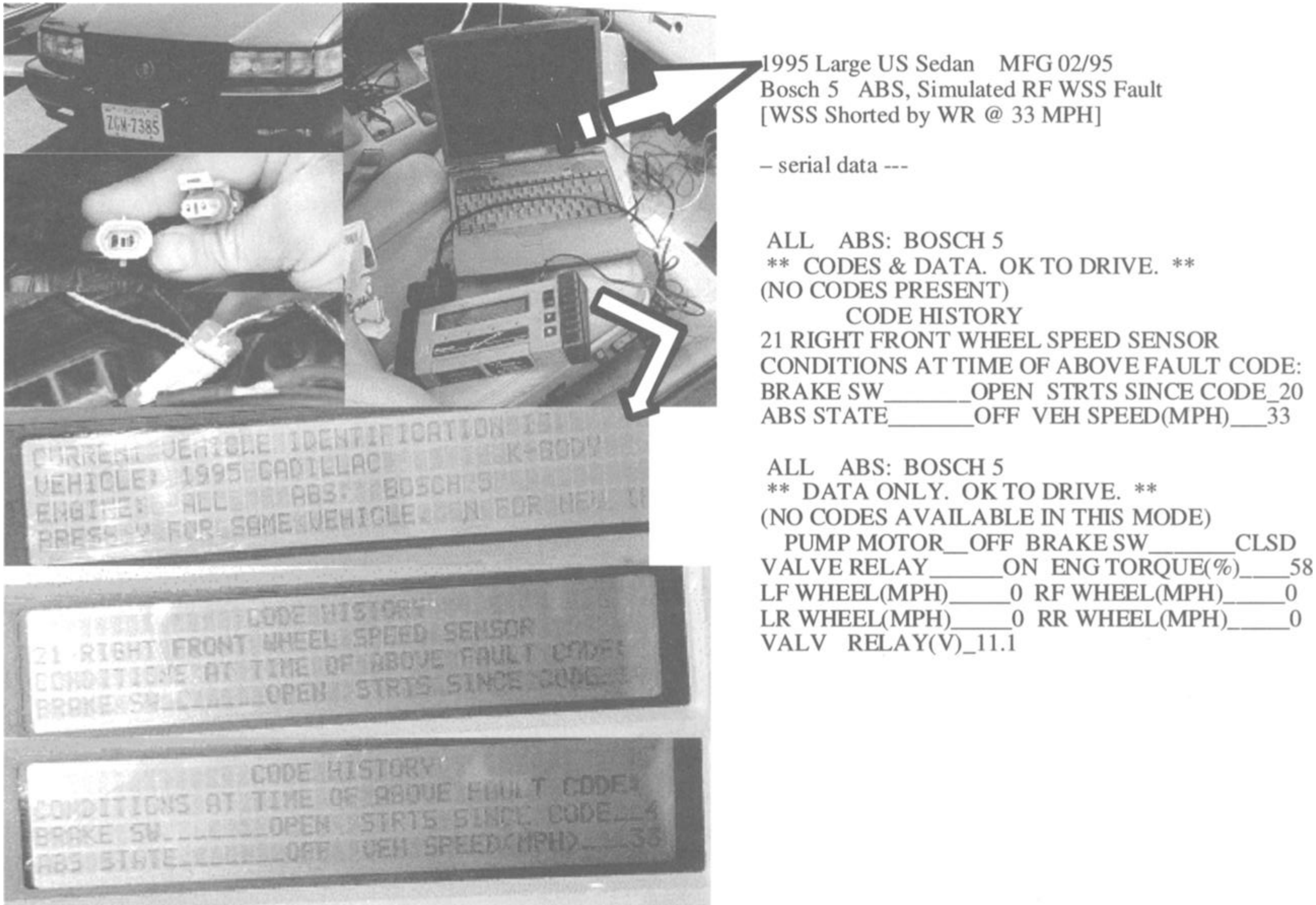


FIG. 1.18—Simulated right front wheel speed sensor fault in a Bosch 5 ABS system on a domestic 1995 model year vehicle. Data documenting EBCM EEPROM freeze frame storage read using a Snap-On MT2500 scanner.

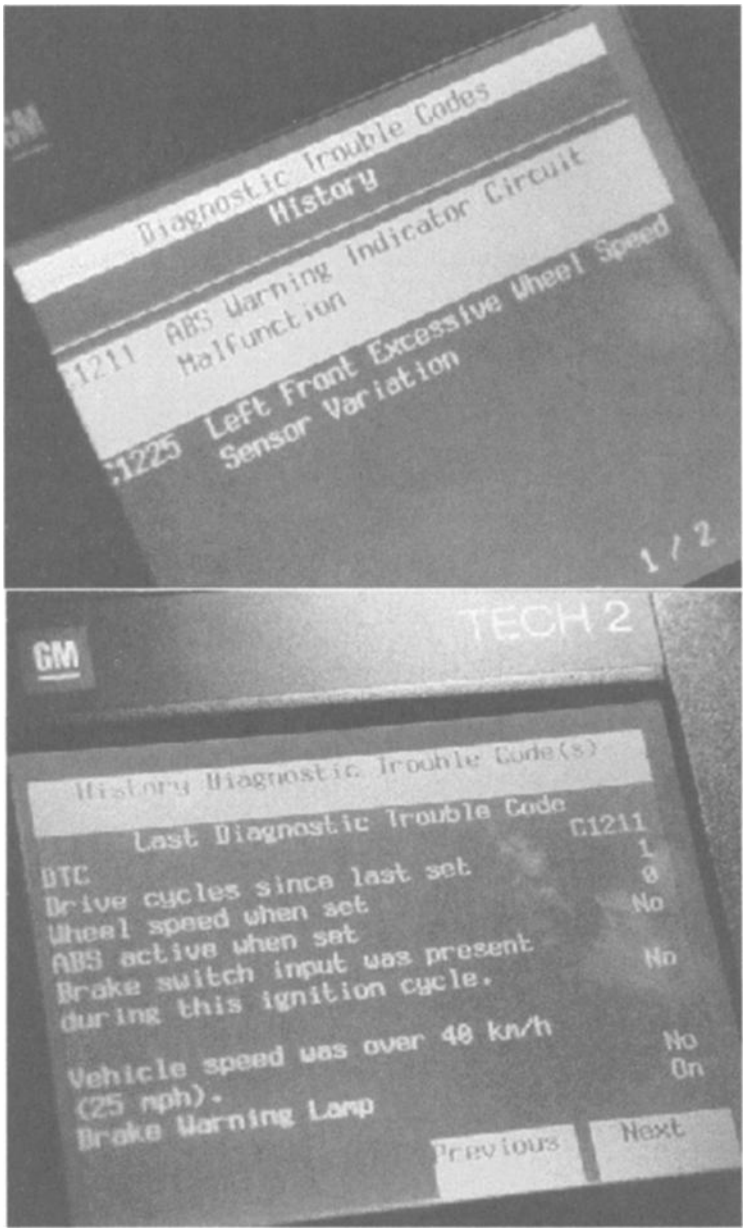


FIG. 1.19—DTC freeze frame data for last OBD-II DTC (C1211). Codes obtained from a 1990 domestic model year truck ABS ECU. Data read using a GM Tech 2 scanner.

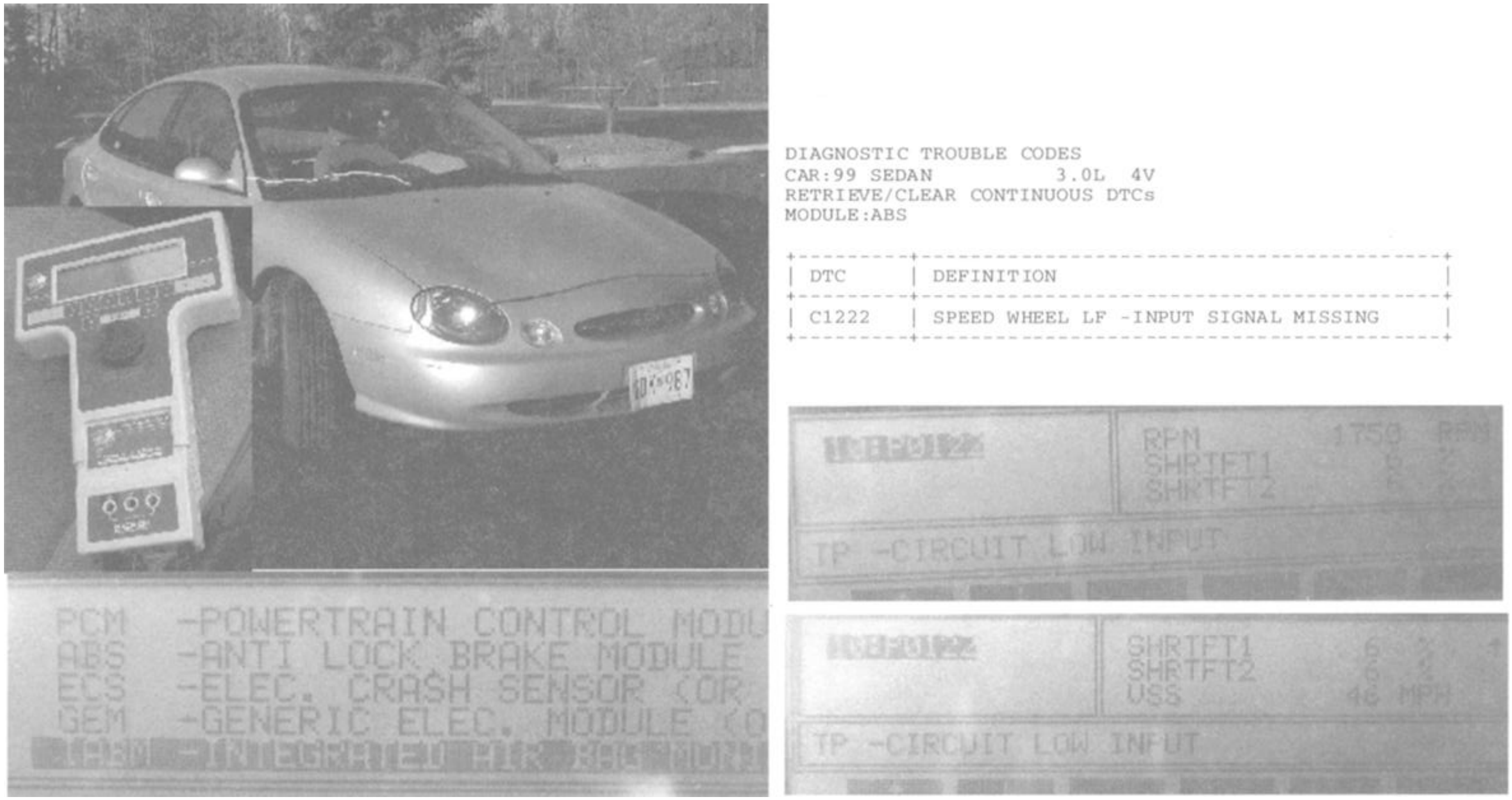


FIG. 1.20—Data from simulated faults in a PCM and an ABS ECU in a 1999 domestic model year vehicle, showing DTC P0122 and its associated freeze frame recording at 46 mph and 1750 rpm. Data read using a Ford New Generation Star Tester.

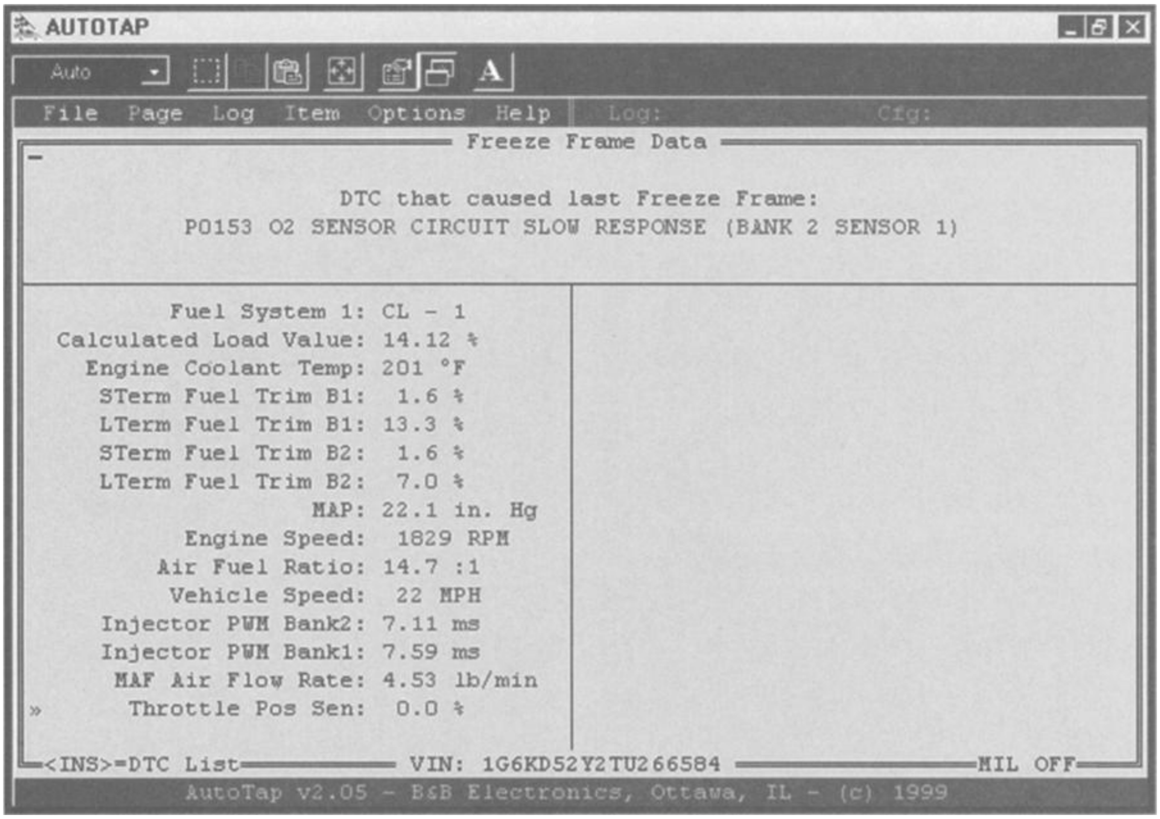


FIG. 1.21—DTC P0153 freeze frame in a 1996 domestic model year PCM showing 22 mph, 1829 rpm and 0% throttle position. Data read using B&B Electronics AutoTap 12 laptop computer interface.

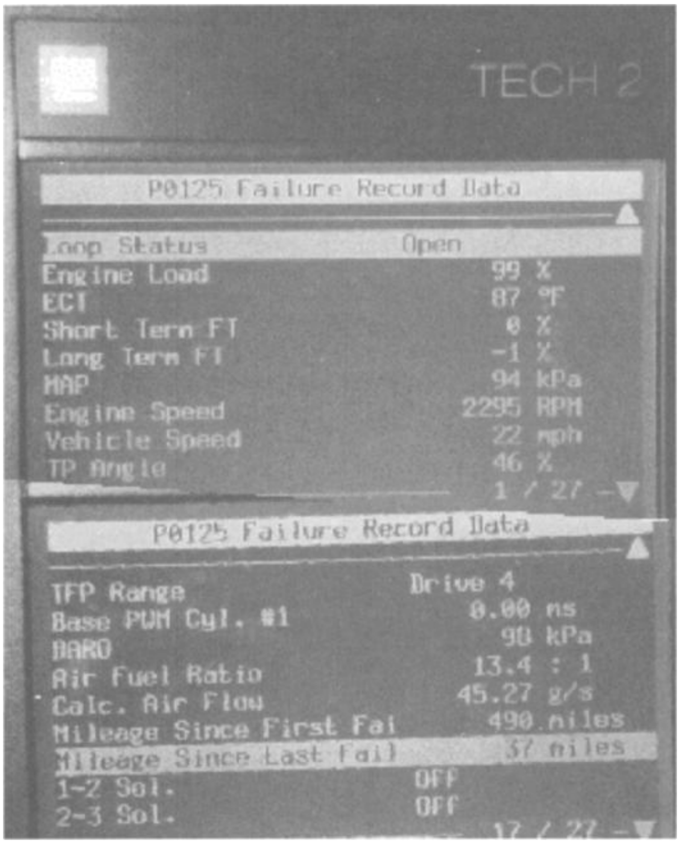


FIG. 1.22—DTC P0125 freeze frame recording in a 1998 domestic model year PCM showing 22 mph, 46% throttle position and 37 miles since last failure. Data read using a GM Tech 2 scanner.

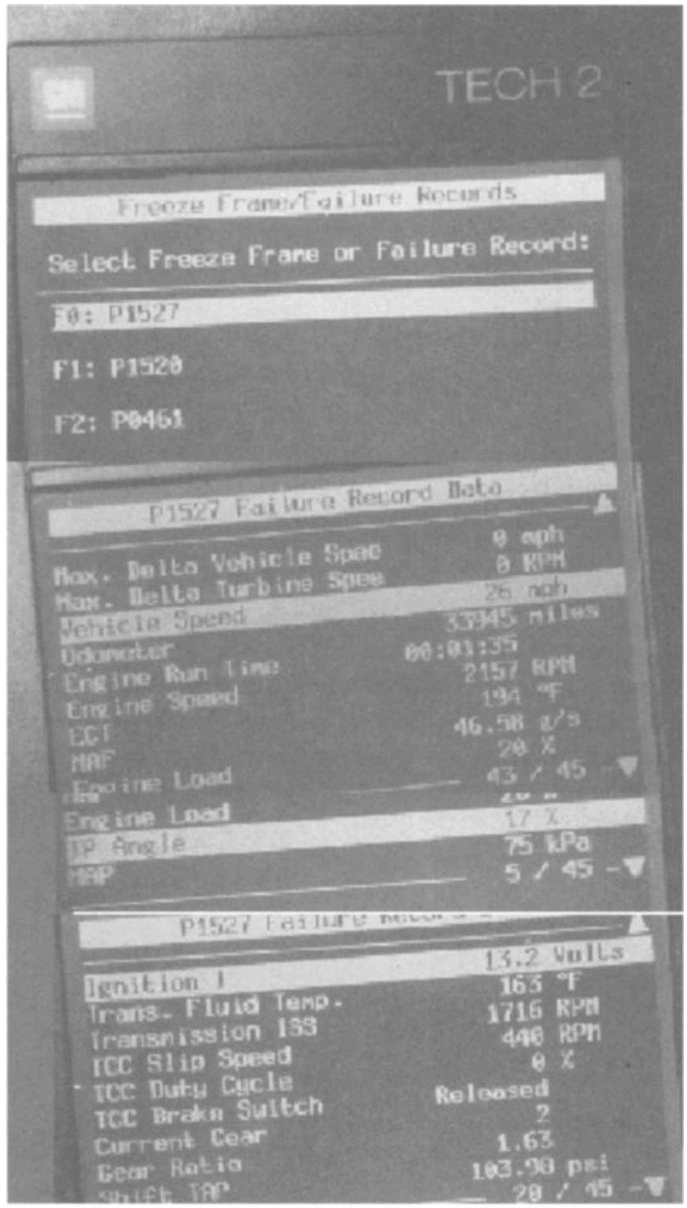


FIG. 1.23—DTC P1527 freeze frame from a 1998 domestic model year showing 26 mph, 2157 rpm and 17% throttle position. Data read using a GM Tech 2 scanner.

TABLE 1.6.2—Example DTCs and snapshot data useful in crash investigations.

		Snapshot Parameters Available										
DTC #	DTC Name	Ignition Cycles Since Set or ODO Since Set	Ignition Cycle at Set or ODO at Set	Brake Applied at Set	ABS Active at Set	Vehicle Speed at Set, mph	Wheel Speed at Set, mph	Throttle % at Set	Engine RPM at Set	Engine Temperature, °F	Engine Run Time, Hr: Min:Sec	Example ECU
P0118	ECT Sensor Open					25		0.4	966	−40		Example of simulated emissions fault set at known vehicle speed on 1998 domestic SUV. See Fig. 1.16
None	Shows ECU P/Ns											Example showing ECU P/Ns from 1995 European sedan. See Fig. 1.17
21	RF WSS	4 cycles		N	N	33						ABS, Bosch5, 1995, see Fig. 1.18
C1211	ABS MIL	1 cycle		N	N	>/<25	0					ABS, Kelsey-Hayes 4WAL, 1999, see Fig. 1.19
C1225	LF WSS											
P0122	TPS Low					46						Domestic PCM, ABS ECU, see Fig. 1.20
P0153	O2 Slow Response					22		0	1829	201		Domestic PCM, see Fig. 1.21
P0125	ECT Excessive time to closed loop	37 mi				22		46	2295			Domestic PCM, see Fig. 1.22
P1527	Transmission pressure switch		33945	N		26		17	2157		0:1:35	Domestic PCM, see Fig. 1.23

Geometric Conventions, The Physical Laws of Motion, Acceleration Models, and Numbering Systems[1]

2

2.1 GEOMETRIC CONVENTIONS, VEHICLE TRAJECTORIES, AND PRINCIPAL DIRECTION OF FORCE (PDOF)

AS WITH A DESCRIPTION OF ANY MECHANICAL SYSTEM, we must first define a standard set of parameters, coordinates, and terms of reference. Global vehicle position and velocity are described in terms of three global axes defined by two SAE standards. SAE J670e, Vehicle Dynamics Terminology (SAE 1976), defines vehicle direction, motion, and travel with respect to three global axes as shown in Fig. 2.1 (Fig. 2 from SAE J670e). These are signed axes (i.e., there is a + and − direction), and one has to carefully coordinate the SAE J670e arrowheads to + signs when formally discussing vehicle motion. In Fig. 2.1, the +X axis is the forward longitudinal direction, the +Y axis is the right side direction, and the +Z axis is the down direction. These signed axes are very precisely defined in SAE J211, Instrumentation for Impact Test (SAE 1988). For clarity, the axes are clearly signed and labeled in Fig. 2.2.

With our defined SAE axes, we can note the position of an object in global space, but to fully characterize the dynamic conditions of that object in a crash, we must also refer to the time interval between changes in spatial positions. If we identify the crash object conditions we can now identify these object conditions as *primary parameters* and *derived parameters* as follows:

A. Primary Parameters
   1. X-axis position
   2. Y-axis position
   3. Z-axis position
   4. Time with respect to a reference (such as seconds after first contact)

B. Derived Parameters
   1. Displacement (the vector resultant of successive positional differences in time)
   2. Velocity (the result of dividing displacement by the time over which the displacement took place)
   3. Acceleration (the rate of change in velocity over two, or more, velocity calculation periods)
   4. Jerk (the rate of change in acceleration over two, or more, acceleration calculation periods)
   5. Energy (the product of force times distance)
   6. Impulse (the product of a force exerted times time)

Successive changes in position along the fixed global axes describe the vehicle spatial position at each instant in time.[2] We define changes in position as displacement, but since displacement of a vehicle is not always exactly along an X, Y, or Z axis, this displacement takes the form of a vector in space, generated from components along those three axes.

If we document each displacement (change in axis position) after equal unit time periods, we can describe each axis displacement, divided by the time to accomplish that displacement, as the axis velocity. If we perform a vector addition of the displacement in all three axes, we will have the resultant velocity vector in three-axis global space.

Similarly, when something impacts a vehicle (or a vehicle impacts it), we can describe the cumulative resultant change in vehicle velocity as a velocity change vector (Delta V) with respect to the three global vehicle axes. We shall shortly see that all Delta Vs come about because of an application of force to cause that change, and, thus, it is common in Reconstruction science to refer to a Delta V as occurring along a principal direction of force (PDOF) vector.

Normally this happens in one plane, i.e., a road surface, where only the X and Y axes are considered. With this simplification, the PDOF is typically described as a polar vector in the road plane, with a radial direction described in terms of the hour hand of a clock face.[3]

Figure 2.3 shows a typical right front impact damaged vehicle; Fig. 2.4 shows the same vehicle with SAE J211/J670e axes superimposed. Figure 2.5 shows the result of a reconstruction analysis where the equivalent barrier Delta V has been calculated to be 20.31 to 22.35 mph, entering the vehicle along a PDOF of 22 to 24° to the right of the X axis. As an alternate reference, the PDOF is also shown on a clock face in Fig. 2.5.

As introduced above, what is actually entering our Fig. 2.5 vehicle is an object that is imparting an impact force to the vehicle in a direction of 22 to 24° to the right of the X axis, and that impact force is serving to retard the pre-force vehicle velocity.

In order to continue with our analysis of vehicle response to an impact force input, we must discuss the physical laws

[1]Portions of this chapter may be similar to, or reprinted from, Chapter 2, "Air Bag System Analysis," *Forensic Accident Investigation: Motor Vehicles—2, Vol. 2*, with the express permission of the publisher, Matthew Bender & Co, Inc., a part of LEXIS-NEXIS.

[2]There is a similar axis system for the local environment within the vehicle and these axes, identified as the "fixed coordinates of the vehicle," are used to evaluate occupant movement within the vehicle. Thus, when describing an unrestrained occupant driver moving toward the steering wheel in a crash, we are describing a free body movement with respect to the fixed coordinates of the vehicle, and this phrase is key in describing the "5-30" rule later in Chapter 3.

[3]Thus, the PDOF is typically described either as a force entering the vehicle impact point at *nn* degrees offset from the longitudinal axis or as a *clock-time vector*. Additionally, a clockwise angle is positive, while a counterclockwise angle is negative.

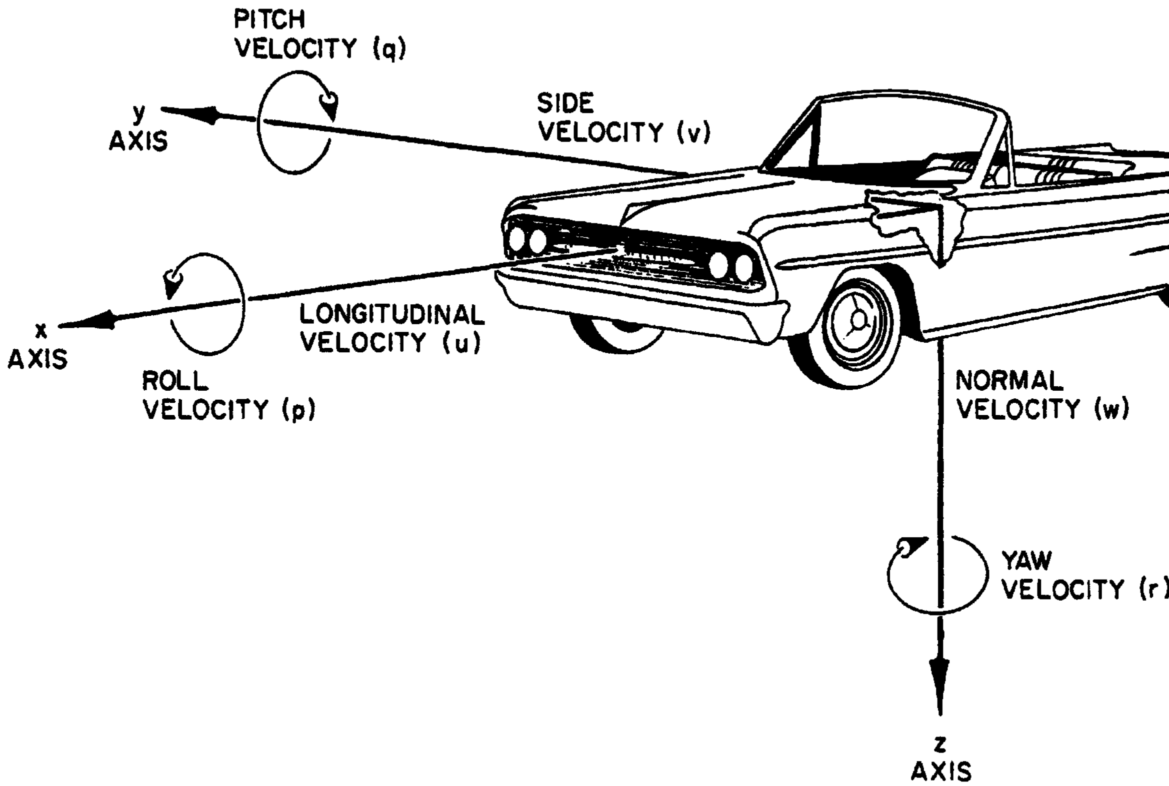


FIG. 2.1—Vehicle direction and control axis systems. (Reprinted with permission from SAE document J670e, © 1976, Society of Automotive Engineers, Inc.)

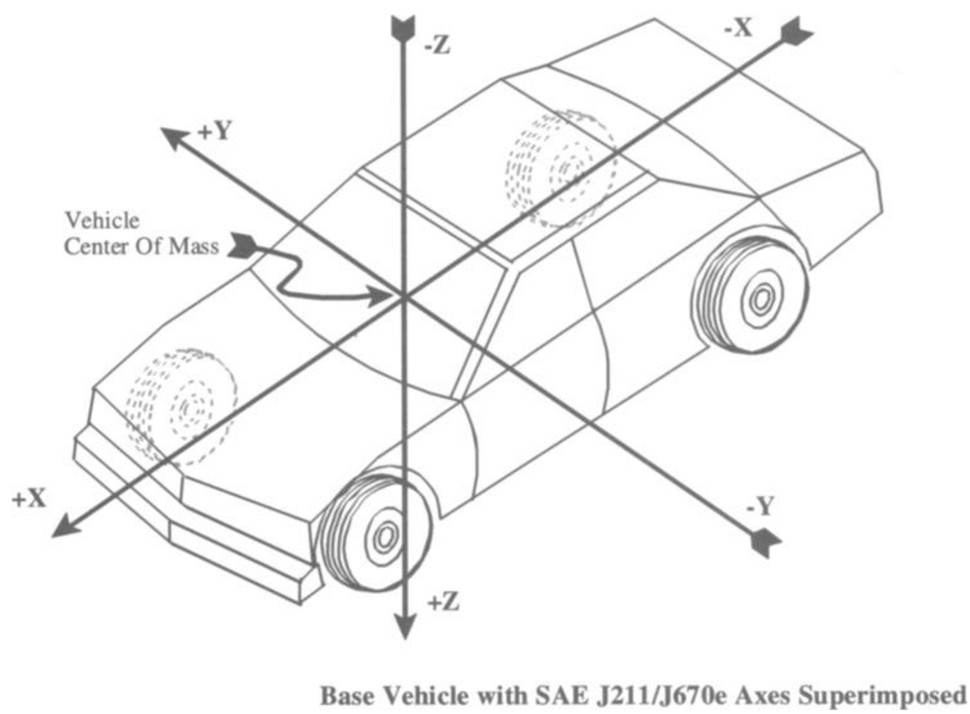


FIG. 2.2—Vehicle axis system with signed SAE J211/J670e directions and labels.

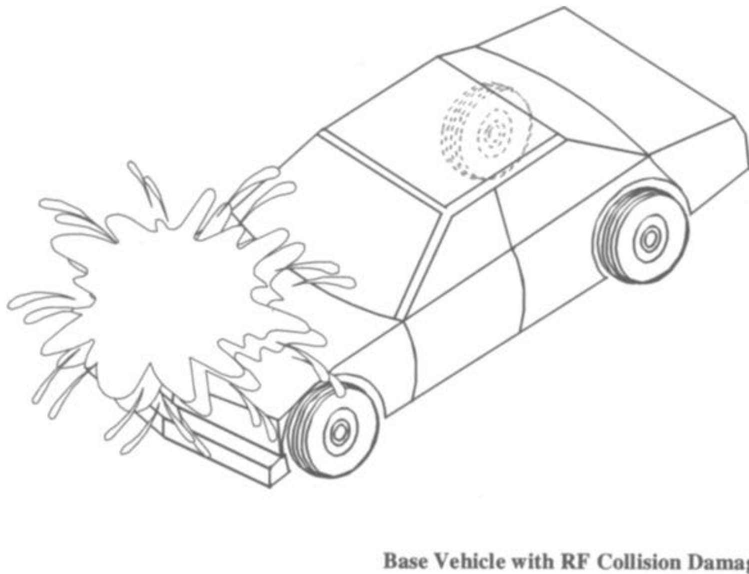


FIG. 2.3—Typical post-crash vehicle with right front collision damage.

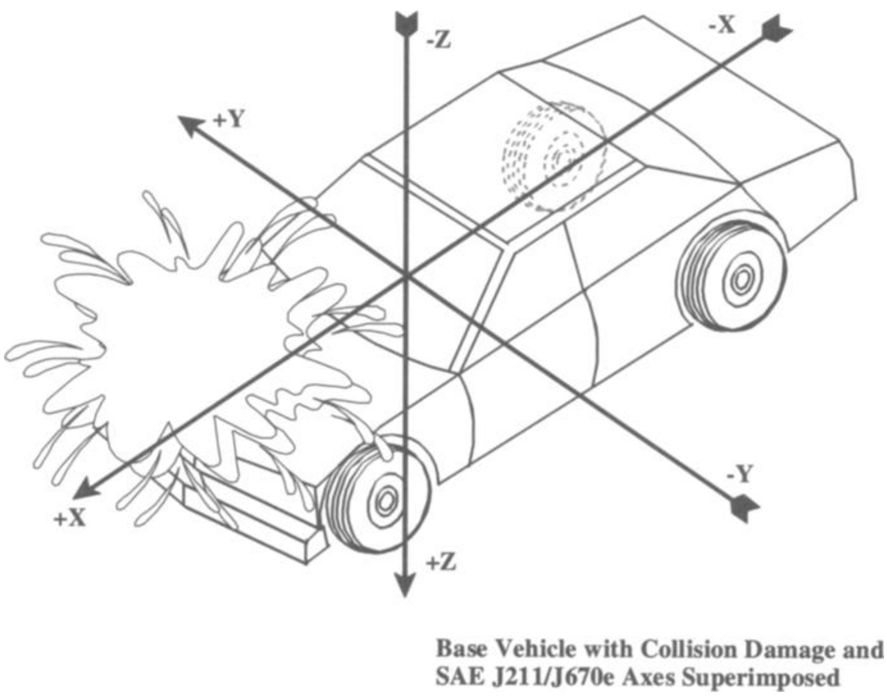


FIG. 2.4—Typical post-crash vehicle with SAE J211/J670e axes superimposed.

that show how an impact force causes a change in velocity of the vehicle.

2.2 THE PHYSICAL LAWS OF MOTION

Every object has a mass, *m*, and our study of basic vehicle dynamics is based on Newton's three laws of motion regarding changes to the state of that mass. They are described as follows (Hausmann and Slack 1957; Smith and Cooper 1957):

1. A body (mass, m) at rest will continue to remain at rest, or a body in motion will continue to remain in motion, unchanged, until it is acted upon by an outside force, F. In other words, a body's momentum (mv) does not change unless it is influenced by an external force.
2. If a body (mass, m) is acted upon by an outside force, its initial momentum (mv_1) will change to (mv_2), proportional to the magnitude of that force and the time that force is applied.

$$Ft = mV_2 - mV_1 = m\,(V_2 - V_1)$$

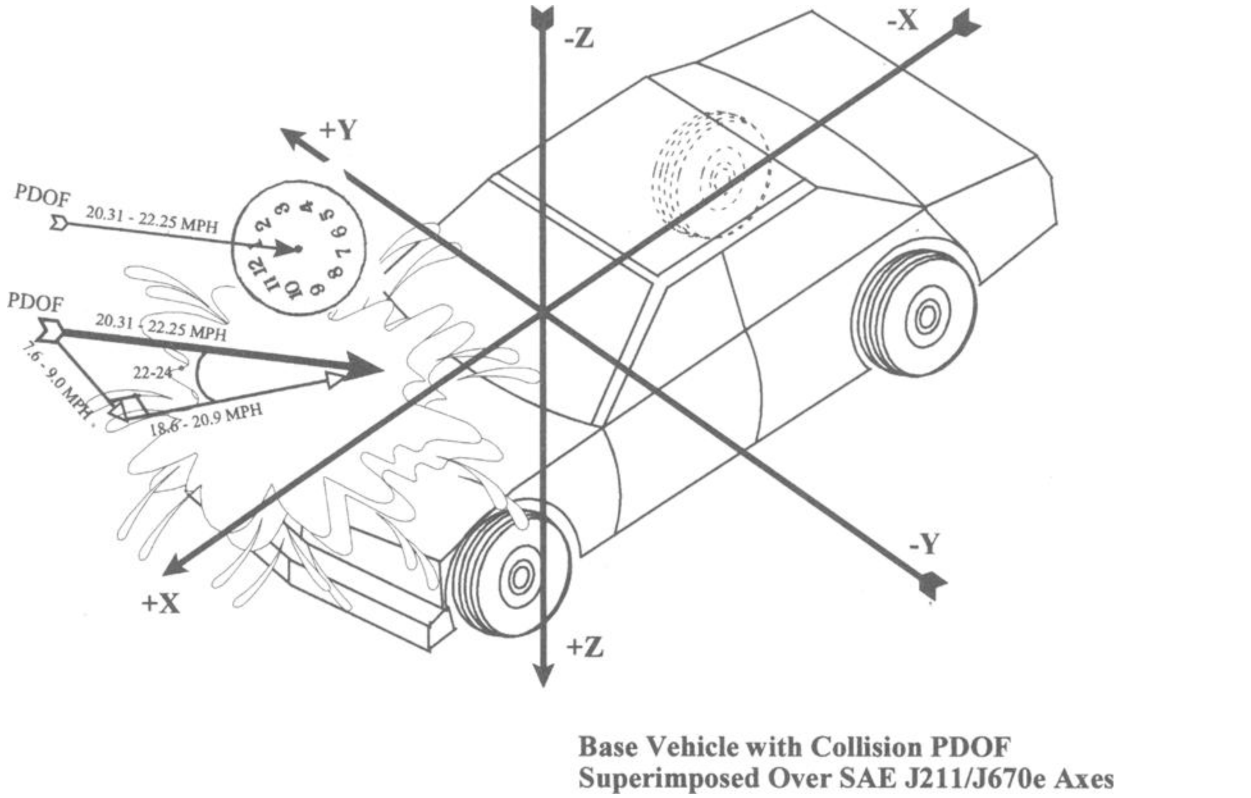


FIG. 2.5—Typical post-crash vehicle with PDOF vector superimposed on SAE J211/J670e axes and on a clockface.

If we let $V_2 - V_1 = \Delta V$, then $Ft = m\,\Delta V$. Rearranging our equation and dividing both sides by t, $F = m(\Delta V/t)$. But, the rate of change in velocity per unit time $(\Delta V/t)$ is defined as acceleration, or $a = \Delta V/t$. Thus, $F = ma$. In other words, a body at rest, or in constant motion, will accelerate in the direction of the input force vector, F.[4]

3. For every force acting upon a body (mass, m), there is an equal and opposite force acting on something else. For vehicle collisions, this means that a force or impulse acting on a subject vehicle will be balanced by an equal and opposite force acting on the object it collides with.

Rearranging our acceleration equation above, we can state that any velocity change, ΔV, in a time period, t, is the product of acceleration times time, or

$$\Delta V = at$$

This is valid for both long and short time intervals. As we break up the crash period into finer and finer time intervals (typically 1 ms or less), we have n incremental time segments of a fixed and known duration ($t_{segment}$), and we can evaluate the incremental velocity change during each time segment (ΔV) as the average segment acceleration, $\langle a \rangle$, times the duration of that $t_{segment}$, or

$$\Delta V_n = \langle a_n \rangle \ t_{segment}$$

Since a force input is actually the root cause of the vehicle deformation and consequent loss of vehicle velocity, we can now look at our reconstructed ΔV and PDOF diagram, Fig. 2.5, and substitute a force input as shown in Fig. 2.7.

Further refining our view of the force input, we know that the force input is not a constant, but varies during the time of the crash deformation (because the vehicle stiffness varies with crush depth). Referring to Fig. 2.8, we can visualize the varying force input at successive sample times. Because we have computer-clocked samples, each $t_{segment}$ is evenly spaced, and the unit segment times are all identical.

$$t_{segment} = t_{n+1} - t_n = \text{unit segment time}$$

Each ΔV_n adds or subtracts its velocity from the immediate past velocity. We can sum (accumulate) the velocity increments in all of the segments (ΔV_n) to determine the total velocity change (gain or loss) after n samples. This can be expressed as follows:

$$\text{Cumulative Velocity Change}|_{n\ \text{samples}} = \Sigma\Delta V_1 + \Delta V_2 + \Delta V_3 + \cdots + \Delta V_n$$

This accumulation process is shown graphically in Fig. 2.9.

[4]This is graphically shown in Fig. 2.6, where three types of force inputs to a vehicle, engine drive force, braking friction force, or collision force, cause engine acceleration, braking deceleration, or crash deceleration, respectively.

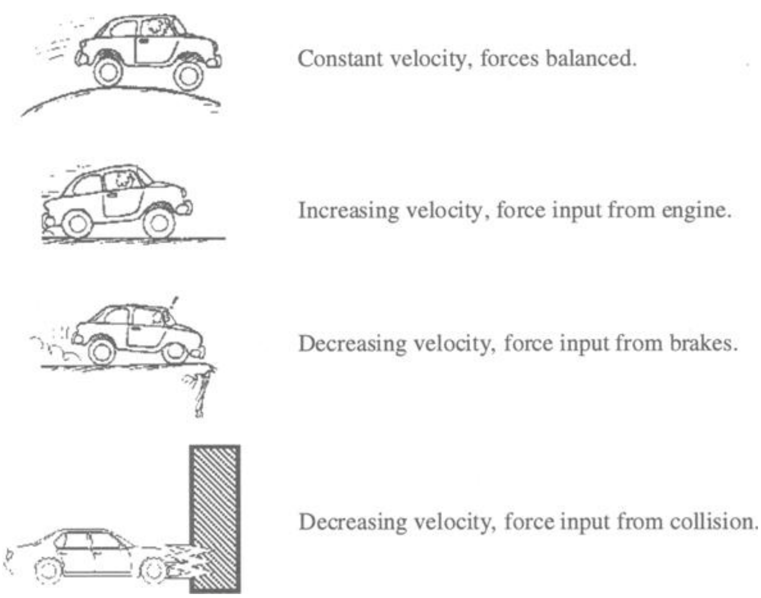


FIG. 2.6—Conceptual illustration showing that force causes acceleration, which causes a change in an object's velocity.

Contemporary vehicle collision detection systems all use continuously sampling accelerometers and microprocessor electronics with crystal clock control to accomplish the unit time sampling described above. These uniform unit time intervals (i.e., segment times) are typically 1 ms or less.

The microprocessors used in these applications typically have integrated analog/digital converters (ADCs), which are used to sample the continuous values of vehicle acceleration (after a turn-on threshold is crossed). The microprocessors also contain numeric registers which are accumulating unit interval values ($\Delta V_1 + \Delta V_2 + \Delta V_3 + \cdots + \Delta V_n$) to produce an interim accumulated Delta V at any point during the event. When the unit interval acceleration falls below a turn-off threshold, the event can be said to be ended, and, thus, the accumulating register will contain the cumulative velocity change, or ΔV_{event}.

During the progress of the crash pulse, the accumulating register contains a time varying value, $\Delta V_{\text{to-that-time}}$, which can be compared values of $\Delta V_{\text{to-that-time}}$ for known test crashes. Since the known test crashes have known injury potential, this comparison can be used to determine if an SRS restraint should be deployed.[5]

2.3 ACCELERATION MODELS

Most crash tests are run against barriers, and the remainder are vehicle-to-vehicle and pole-impact tests. An example center of mass acceleration pulse from a barrier test crash is shown in Fig. 2.10.[6] Enough tests have been run to determine the general waveform of a crash acceleration pulse is most like a *haversine function*,[7] shown in Fig. 2.11. This function is the one most commonly used to *model* crash events, but others are possible.

Before defining and testing the haversine function as a model, let us recall that, if we divide up the crash pulse into unit time segments samples, we can calculate the velocity change in each time segment as

$$\Delta V_n = \langle a_n \rangle \, t_{\text{segment}}$$

and that the cumulative velocity change in an event (ΔV_{event}) can be stated as

$$\Delta V_{\text{event}} = \Sigma\, \Delta V_1 + \Delta V_2 + \Delta V_3 + \cdots + \Delta V_n$$

where, typically, n samples (that exceed a threshold value) are recorded as valid data.

We can determine the parameters for each ΔV_n by inspecting time segments from a crash acceleration waveform. This method of determining ΔV_{event} is a form of numeric integration of a complex and irregular acceleration waveform, and, as the segments are made short enough, it will give an increasingly accurate answer for ΔV_{event}.

[5] A similar methodology, deriving acceleration from variations in wheel speed input and/or other chassis accelerometers, is used by ABS and TCS systems.

[6] Taken from NHTSA FMVSS 208 Rigid Barrier Crash Test on a mid-sized domestic sedan, 29.3 mph, 47.2 kph. Crash data are available from http://www.nhtsa.dot.gov/.

[7] The HAVERSINE is a periodic function derived from the trigonometric sines and cosine functions. The root function (VERSINE) was developed and originally used for celestial navigation. The VERSINE (or versed sine) of Angle A is 1–cos(A). HAVERSINE (A) is defined as one half the versine, or hav (A) ½(1–cos(A)). This form is also used in electrical engineering where it is known as the "raised cosine."

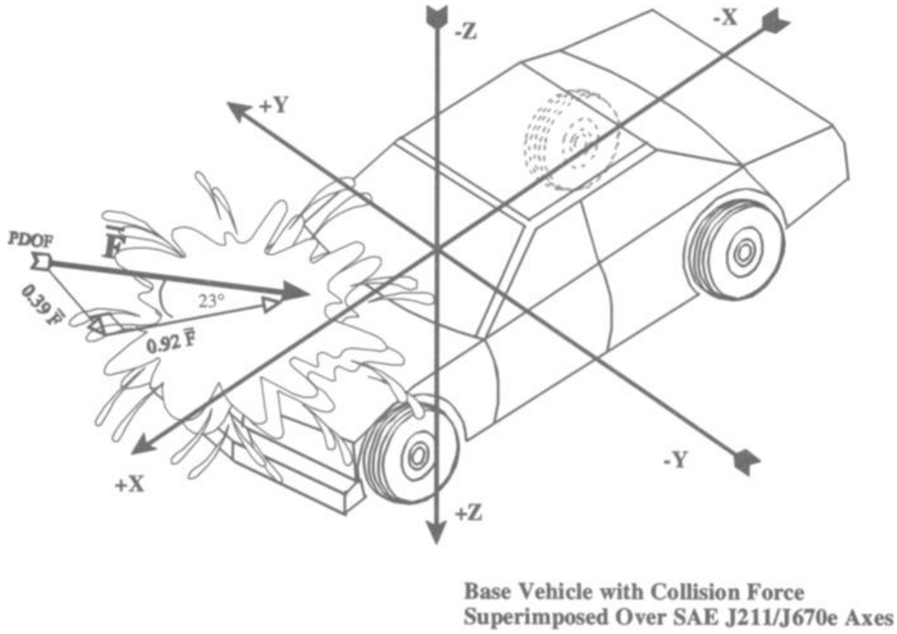


FIG. 2.7—The crash pulse showing that a force vector is actually the cause of impact damage and change in velocity.

The reader should note that we have described the front end of a crash event. In barrier and most other crashes, another component of such an event, restitution of the crushing chassis structure, produces a velocity rebound after the forward velocity has diminished to zero. This rebound velocity adds to the initial approach velocity to produce what reconstructionists call a Total Crash Delta V. For fixed barrier crashes, the Total Crash Delta V always exceeds the barrier equivalent velocity (BEV), and this is further discussed later in this chapter.

2.3.1 Defining and Testing a Crash Pulse Model

It is often desired to characterize a crash event before all samples have been recorded, or to reconstruct a crash event with only limited boundary data such as a_{peak} and t_{pulse}. This can be done if the crash event can be represented by an understood (predictable) mathematical function, such as the scaled haversine.

As we have seen above, a crash pulse is the accumulated sum of force(s) applied during the time segments of a crash. Each applied force increment produces a linearly corresponding acceleration increment. Since we can more easily detect and record acceleration increments, we can characterize a crash event force by studying its successive acceleration/deceleration values in time (and this is called its acceleration waveform). As discussed above, almost all modern crash detection systems utilize solid-state accelerometers to detect and monitor crash events.

When one says that a crash acceleration/deceleration waveform is modeled (approximated) by a particular mathematical function, it means that we can replace the actual deceleration waveform by an understood mathematical one that is a good fit, and that it will give us answers that are close to the real data (i.e., predicting or verifying Total Collision Delta V produced by the accumulated sum of force(s) applied during the crash). A good model:

- approximately tracks the actual wave-form.
- is mathematically understood so that it can be evaluated for different crash pulse characteristics.
- has a total period value of unity, so that it does not influence the modeled variable.

By definition, the haversine function in time is

$$f(t) = \tfrac{1}{2}(1 - \cos(t))$$

The haversine has a period (cycle) that occurs over 2π radians and is shown in Fig. 2.11. The area under the haversine (total area between the haversine and the t-axis) can be shown to be equal to the area in the cross hatched rectangle, or

$$\frac{1}{2}\int_0^{2\pi} (1 - \cos(t))\, dt = \pi$$

When the haversine is scaled in amplitude by dividing it by π then the unit haversine cycle integral becomes 1, and the basic unit haversine cycle integral is,

$$\text{Unit Haversine Cycle Integral} = 1 = \frac{1}{2\pi}\int_0^{2\pi} (1 - \cos(t))\, dt$$

To be a good model, the haversine function model has to be substantially congruent with the real data waveform, and its total summation (integral) has to scale to the summation

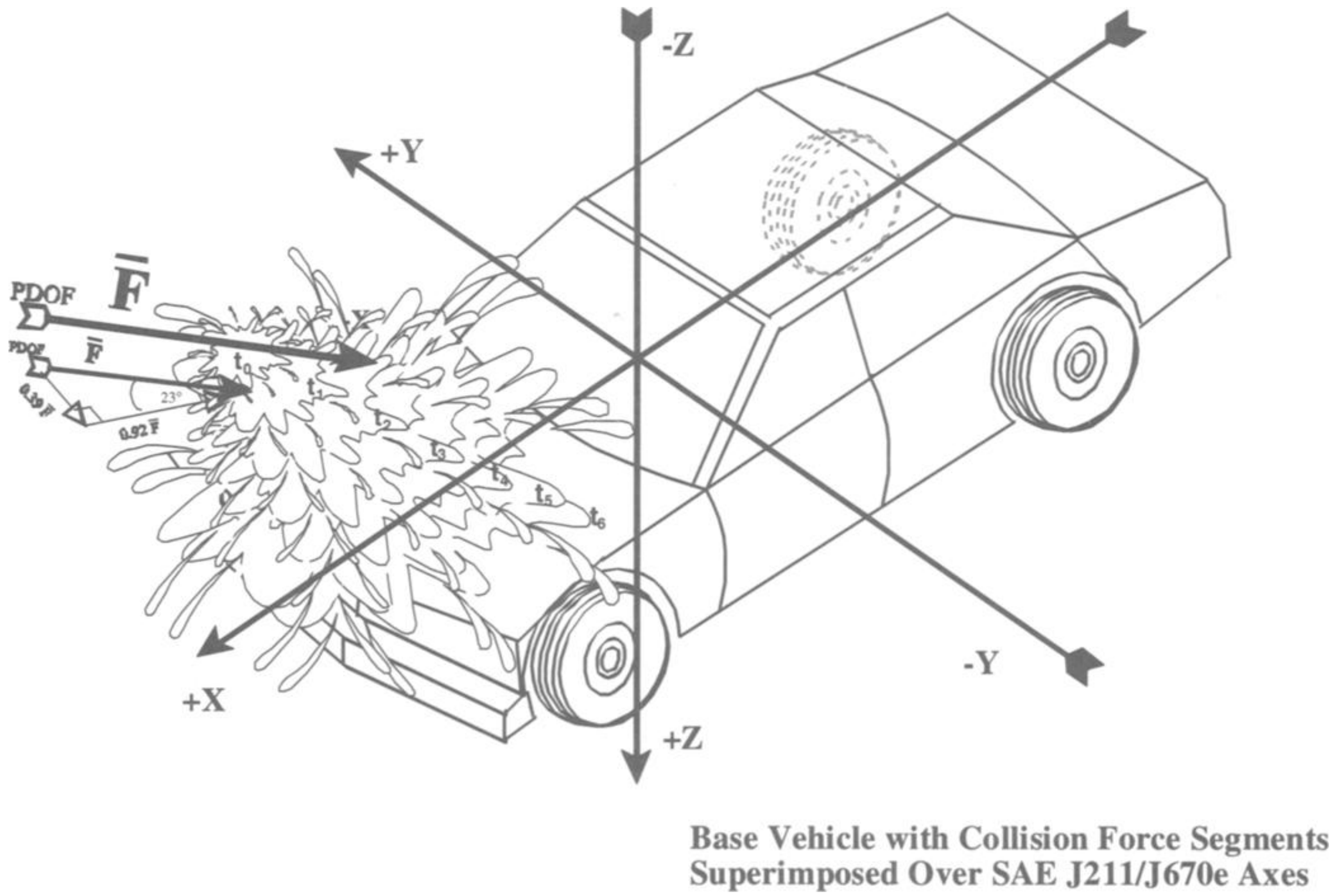


FIG. 2.8—The crash pulse showing that a force vector actually consists of successive force increments in each time segment. These produce an average acceleration in each time segment, which is integrated to produce segment velocity changes. The accumulated (summed) force causes cumulative impact damage and the accumulated segment velocity changes produce a total velocity change (commonly called the cumulative Delta V).

(integral) of the real data waveform so that the model and the real velocities also match.[8]

Crash pulses exist over time periods of approximately 100 ms and have a cumulative Delta V shown as:

$$\text{Cumulative Velocity Change}\big|_{n\ \text{samples}} = \Sigma\Delta V_1 + \Delta V_2 + \Delta V_3 + \cdots + \Delta V_n$$

To create a model, we have to normalize or scale the modeling function to the real acceleration data in order for it to be a useful model. This is accomplished by overlaying the base of the haversine cycle (2π radians) on the crash pulse duration (t_{pulse}), and overlaying the peak value of the haversine on the peak value of the crash acceleration pulse (a_{peak}). The resulting crash pulse acceleration model is

$$a(t) = [a_{peak}]\left[\frac{1}{2}\right]\left[1 - \cos\left(\frac{2\pi t}{t_{pulse}}\right)\right]$$

[8]The model is linearly scaled to the boundary conditions of the actual crash pulse waveform.

This model shows how amplitude scaling is accomplished by multiplying the haversine function by $[a_{peak}]$, and the time scaling is accomplished by substituting the value $(2\pi t/t_{pulse})$ for t in the unit haversine cycle integral.

We have already seen an example of a typical recorded crash pulse in Fig. 2.10. Note that the acceleration is in the −X axis, indicating that the impact force entered the vehicle from the front to the back of the vehicle along the X axis, as in a true frontal crash. If we invert that crash pulse (for the sake of convenience), we can scale a haversine pulse model and overlay it as a "best-fit" on the real crash pulse, as is shown in Fig. 2.12.

Once we have a model, we can now express our total crash event velocity change, ΔV_{event}, in terms of two quantities that are directly measurable: the peak deceleration, a_{peak}, and the pulse duration, t_{pulse}. Assuming the haversine model as the crash pulse approximation, then the integral of the crash pulse (scaled haversine modeling function) is equal to the (scaled) cross hatched rectangle in Fig. 2.11.

Or $$\Delta V_{event} = \int_{t=0}^{t=t\,pulse} a(t)\,dt$$

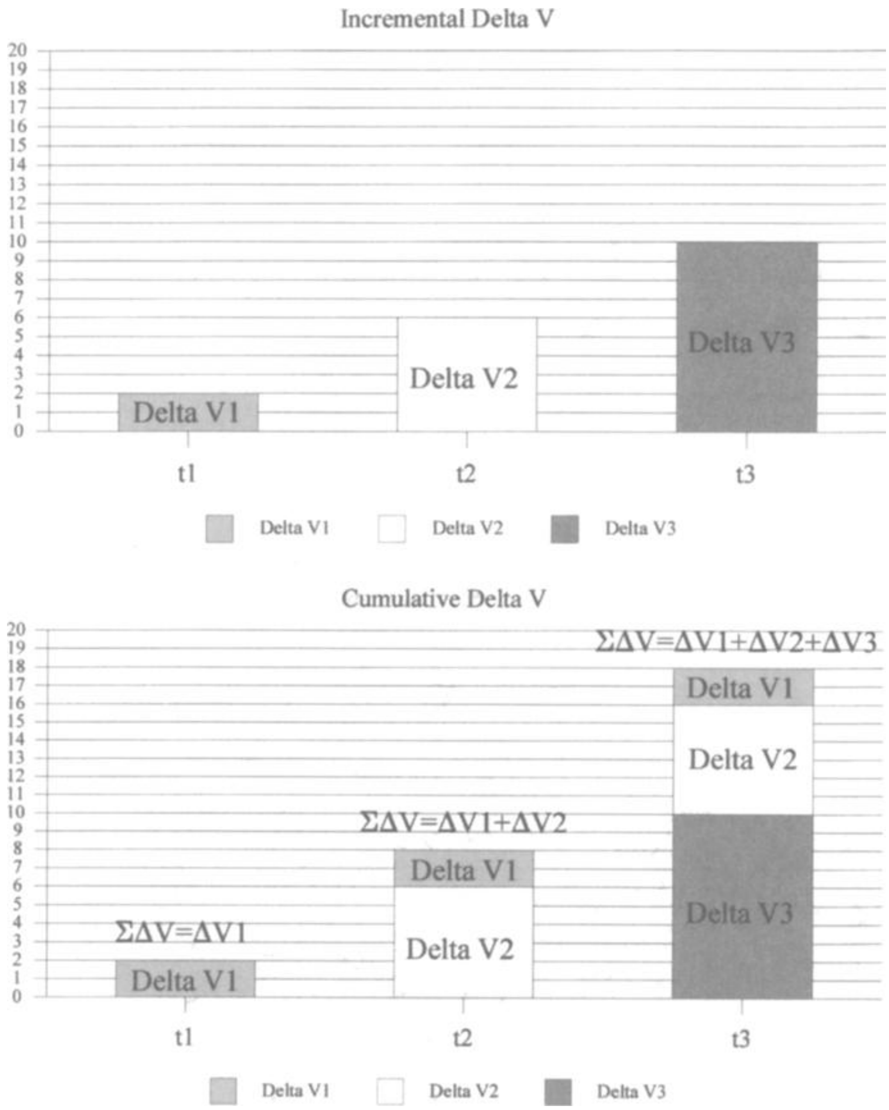


FIG. 2.9—Incremental velocity summing process showing that the accumulated velocity change is the sum of the prior period components.

and consequently,

$$\Delta V_{\text{event}} = \frac{1}{2}\,[a_{\text{peak}}][t_{\text{pulse}}]$$

An exercise comparing a numeric integration to a model function is shown in section 2.3.2 below, and several more are illustrated in the case studies in Chapter 6.

2.3.2 Evaluating the Model Against the Example Crash Pulse

In order to see if our models can accurately predict a barrier equivalent velocity (BEV), we have to take the pre-rebound portion of the acceleration waveform at the center of mass of the test vehicle. That means that we are going to see how closely our analyses of the 0 to 104 ms portion of the Fig. 2.10 acceleration waveform match the known 29.3 mph (47.2 kph) approach speed (BEV). This will be done by comparing a haversine evaluation using a_{peak}, and a pulse duration, t_{pulse}:

$$\Delta V_{\text{event}} = \frac{1}{2}\,[a_{\text{peak}}][t_{\text{pulse}}]$$

to the summation of time sample evaluations,

$$\text{Cumulative Velocity Change}\big|_{n\ \text{samples}} = \Sigma\ \Delta V_1 + \Delta V_2 + \Delta V_3 + \cdots + \Delta V_n$$

and comparing them both to the known approach velocity of 29.3 mph (47.2 kph).

For purposes of our evaluation, we have taken the actual data file used to create the waveform of Fig. 2.10 (recorded and provided at 12 500 samples/second) and bias-corrected and filtered it to create 52 2-ms data segments. This gives us 52 segment acceleration values with $a_{\text{peak}} = 25.6\ G$ at 74 ms and $t_{\text{pulse}} = 104$ ms. Figure 2.13 shows these 2 ms segments

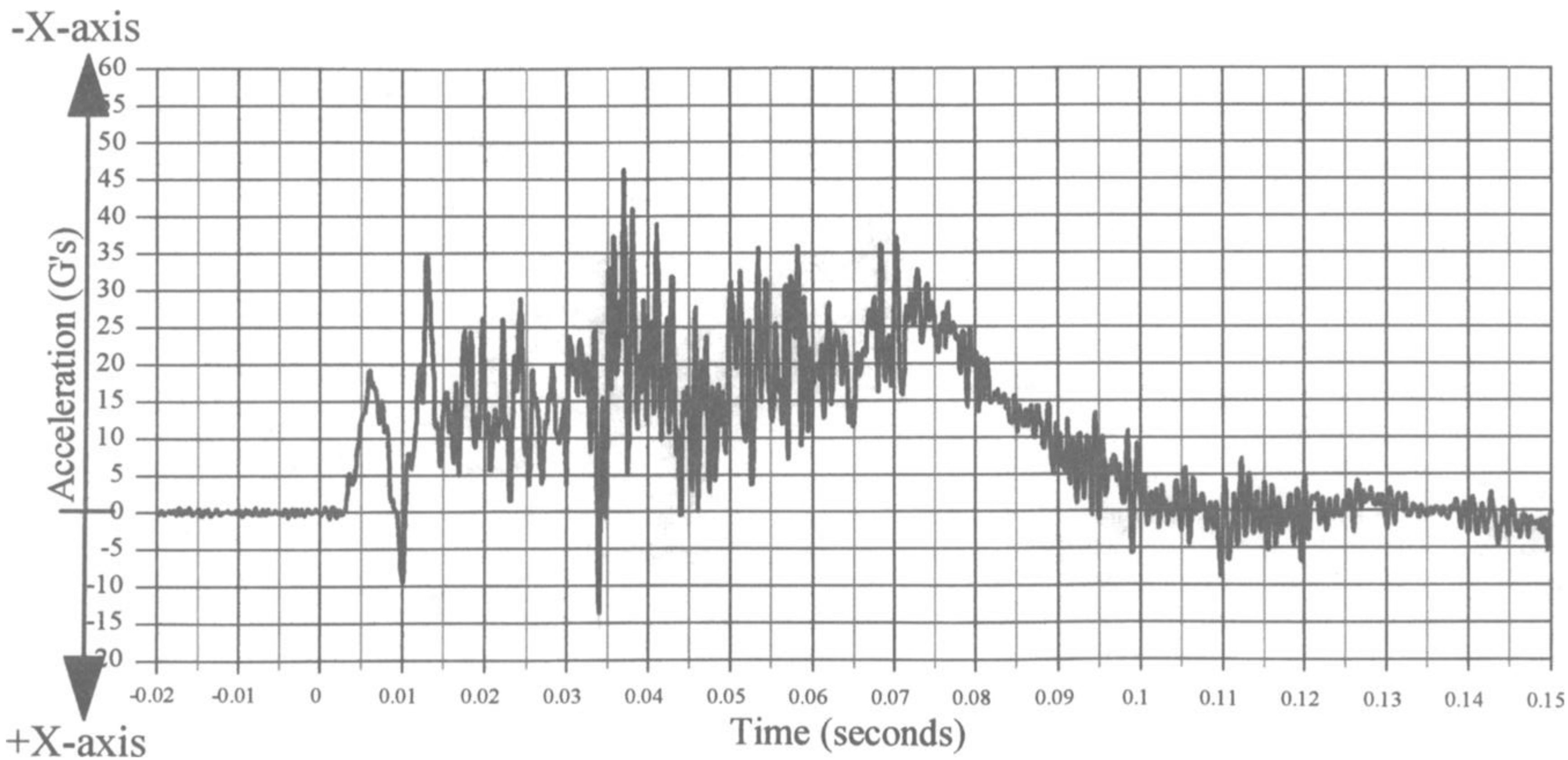


FIG. 2.10—A typical acceleration pulse recorded at the center of mass of a vehicle impacting a fixed barrier at 29.3 mph (47.2 kph). Note that a frontal crash pulse produces −X axis acceleration (or deceleration), per the SAE J211 and J670e conventions shown in Figures 2.1, 2.2, and 2.4 above.

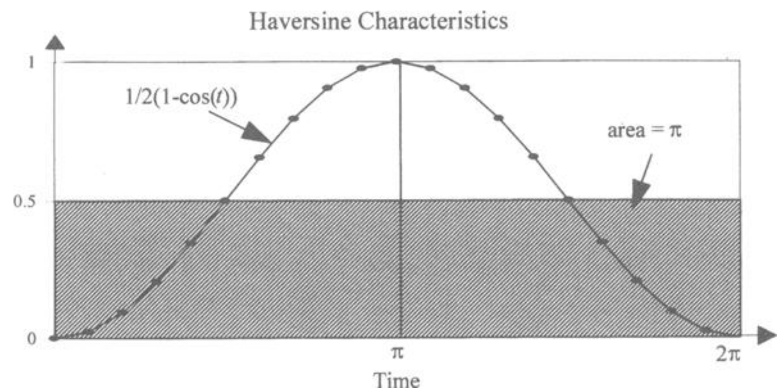


FIG. 2.11—Graphical characteristics of a haversine function.

(i.e., 52 sample intervals over 104 ms) overlaid on the original crash waveform of Fig. 2.10.

Now, we can evaluate the total cumulative velocity change (Delta V) in two ways to examine the consistency of the calculation process and then compare these answers to the measured approach velocity of 29.3 mph (47.2 kph). Remembering to convert to consistent units (ft/s, ft/s^2, s, etc),

$$\text{Peak acceleration} = 25.6\ Gs \times 32.2\ \text{ft/s}^2 = 824.3\ \text{ft/s}^2\ (251.4\ \text{m/s}^2)$$

$$\text{Time} = 104\ \text{ms} = 0.104\ \text{s}$$

Our first calculation, using only the boundary conditions and assuming the haversine model, gives us:

$$\Delta V = 1/2\ [a_{peak}][t_{pulse}] = 0.5\ [824.3\ \text{ft/s}^2]\ [0.104\ \text{s}] = 42.9\ \text{ft/s} = 29.2\ \text{mph}\ (47.0\ \text{kph})$$

Our second method uses the numeric summation of the 52 average acceleration values ($\langle a_{segment}\rangle$) for each time segment shown in Fig. 2.13.

In this exercise, for each of the 52 time segments, the average acceleration values ($\langle a_{segment}\rangle$) are multiplied by the sample time (2.0 ms) to provide the ΔV for that segment ($\Delta V_{segment}$). Then, these segment ΔVs are summed to provide a cumulative velocity change for the entire crash event. This staircase summation process shown in Fig. 2.14 gives us a total cumulative velocity change (before rebound) of 31.6 mph.

Comparing these calculated values to our known approach velocity of 29.3 mph (47.2 kph), the haversine calculation of 29.2 mph was 0.5% low and the numeric integration calculation of 31.6 mph was 7.8% high. These results fall within the accepted 10% tolerances for modeling and reconstruction (Day and Hargens 1989; McHenry Software undated).[9]

[9] Recall also that we have used an accelerometer, which is closest to, but not exactly at, the center of vehicle mass, and that as the vehicle crushes, its center of mass location actually changes as the crush increases.

2.4 EVALUATING COLLISION SEVERITY USING FORCE, ACCELERATION, VELOCITY AND DISTANCE RELATIONSHIPS

Vehicle collision severity can be measured by evaluating physical damage (deformation, penetration and stress propagation).[10] Vehicle physical damage is caused by a force and is proportional to the magnitude and direction of that force and the duration over which that force is applied.

From the relationships discussed above, we know that an applied force causes an acceleration ($F = ma$), and, with respect to vehicles, there are three general types of input forces that are applied:

- engine thrust (causing the vehicle to gain velocity, obtained by adding energy by burning fuel),
- braking (causing the vehicle to velocity loss in a controlled manner, obtained by dissipating energy in the form of heat in the braking friction materials), and
- impact (causing the vehicle to lose velocity rapidly, commonly called a crash, obtained by dissipating energy to deform the vehicle).

Figure 2.6 provides a pictorial illustration of the effects of these forces as applied to vehicles.

Each force application event causes an acceleration, which, over the event time, can be observed as a change in vehicle velocity, ΔV_{event}.

$$\Delta V_{event} = \langle a_{event}\rangle\ t_{event}$$

where $\langle a_{event}\rangle$ is assumed to the constant average-acceleration for the event period,[11] and ΔV_{event} is the vectorial difference between pre-force-application velocity and post-force-application velocity. The total event velocity change is usually referred to as Delta V (ΔV), which is said to be a measure of collision severity. However, we can achieve the same magnitude of velocity loss (negative Delta V) by applying braking forces (2) or by applying impact forces (3), and we can easily see that the deceleration produced by these respective force

[10] Occupant injury severity normally tracks vehicle collision severity and is measured using an AIS scale of 1 to 6 (1 = minor, 2 = moderate, 3 = serious, 4 = severe, 5 = critical, 6 = maximum, untreatable).

[11] As might be derived using the haversine model for example.

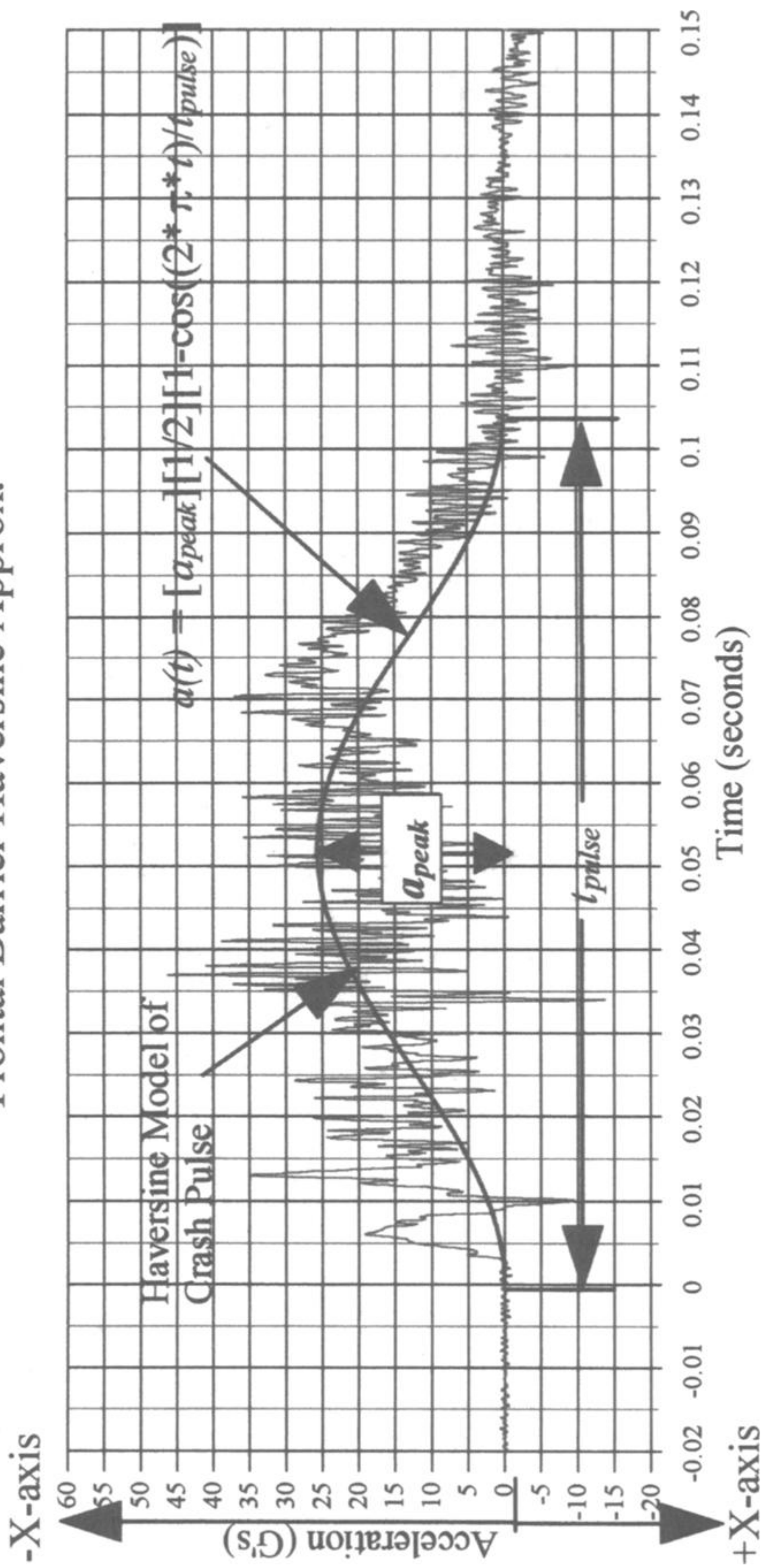


FIG. 2.12—Scaled haversine pulse model on inverted crash pulse of Figure 2.11. Note graphical scaling factors t_{pulse} and a_{peak}.

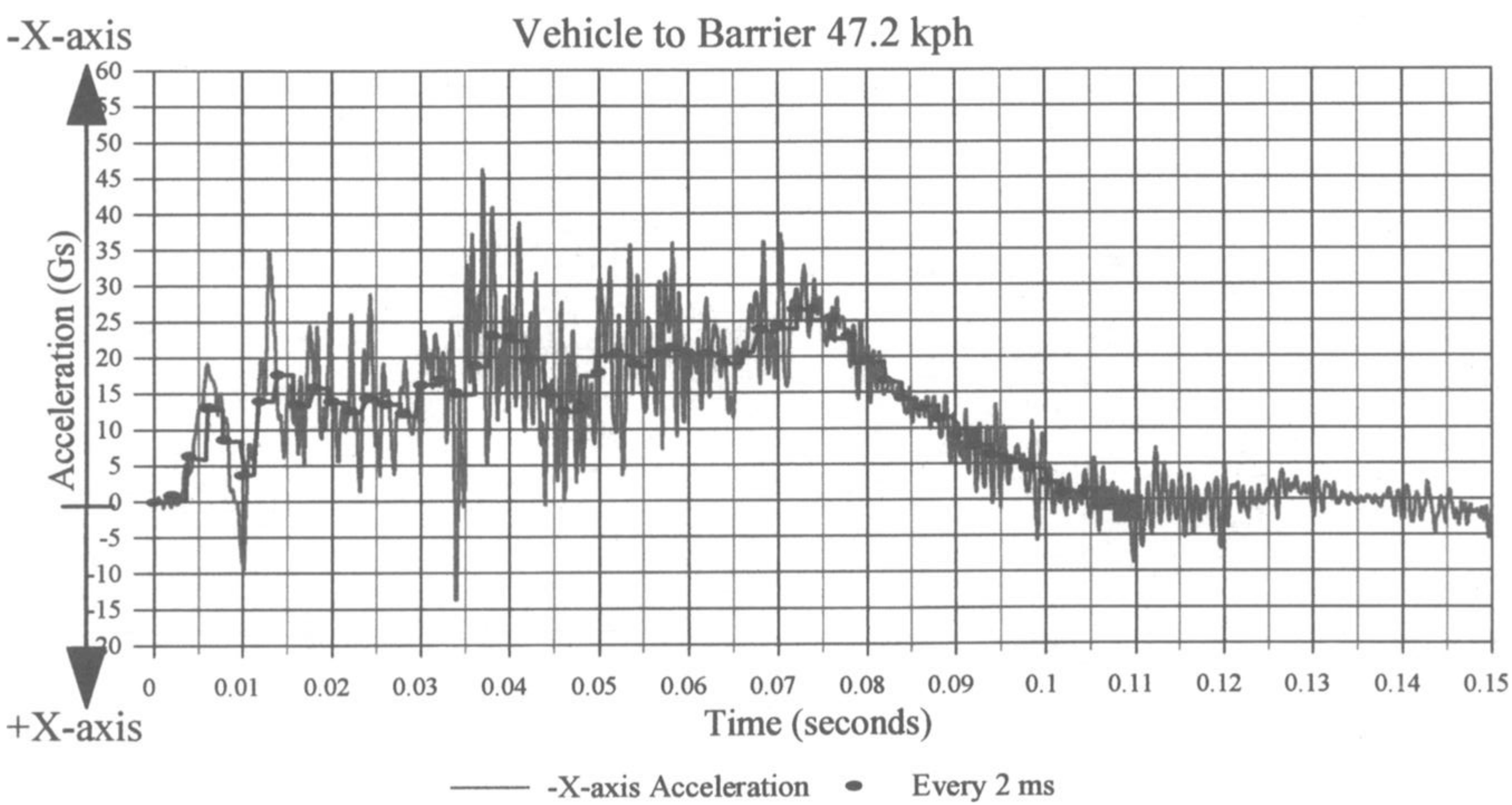


FIG. 2.13—The inverted example 29.3 mph (47.2 kph) longitudinal crash pulse showing step segment approximation to the recorded acceleration waveform.

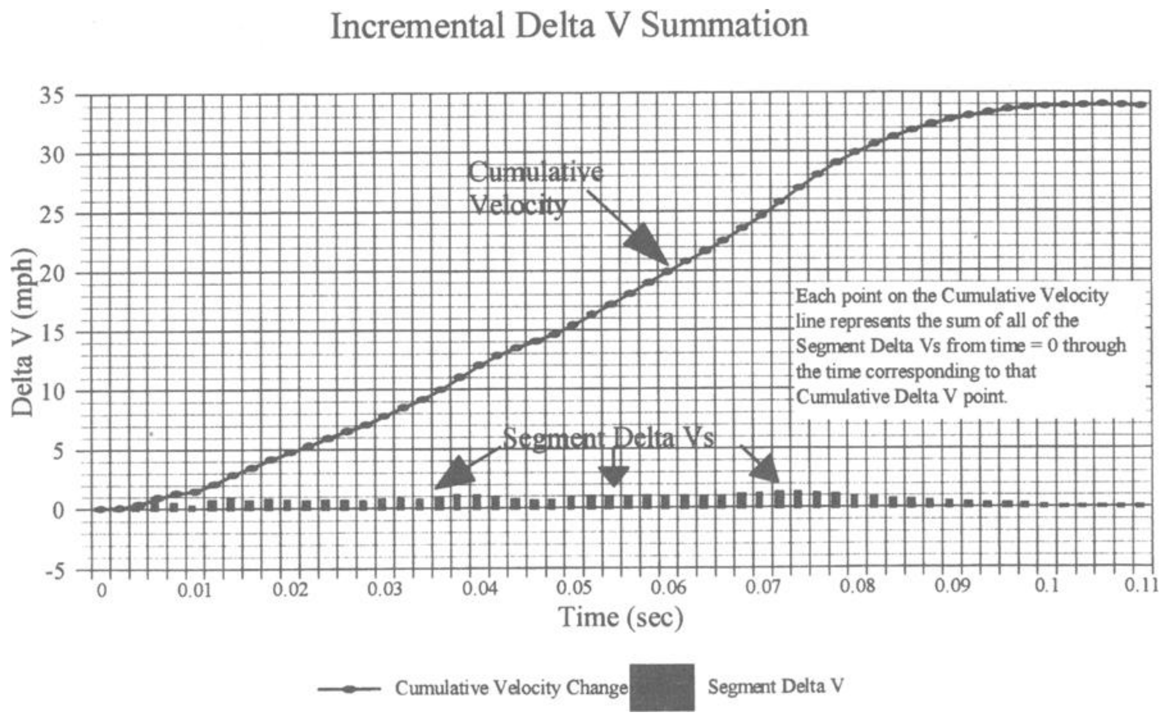


FIG. 2.14—Numeric integration staircase summation of the total velocity change using $\langle a_{segment}\rangle \times t_{segment}$.

inputs ($\Delta V/t_{event}$) is markedly different. This is because ΔV_{event} is the product of a linear function ($\langle a_{event}\rangle\, t_{event}$), and many combinations of $\langle a_{event}\rangle$ and t_{event} can produce the same ΔV_{event}. Conversely, if we keep ΔV_{event} constant, and vary the time in which ΔV_{event} is achieved, we can see that $\langle a_{event}\rangle$ must vary. This is mathematically represented by examining our transposed event velocity change equation:

$$\langle a_{event}\rangle = \Delta V_{event}/t_{event}$$

In the real world, hard braking produces event accelerations in the order of 0.7 *G*s over several seconds, whereas impacts produce event accelerations in the order of 20 to 50 *G*s over 1/10 of a second.

Considering the average event acceleration $\langle a_{event}\rangle$ to be a constant during the event time, an identical velocity loss of 30 mph (44 ft/s, 48.3 kph) can be equally produced by segments consisting of: a braking force producing 0.68 *G*s for 2.0 s, or an impact force producing 13.66 *G*s for 0.100 s (100 ms).

Figure 2.15 provides a graphical illustration of these calculations and shows how identical cumulative velocity losses (ΔV_{event}) can be produced by markedly different deceleration pulses. Since the forces that generate vehicle-crush (and consequent occupant injury) are directly related to the deceleration magnitude, the simplistic use of the term "Delta V" (as implying ΔV_{event}) as used alone without a time reference is an inappropriate descriptor of collision severity (Husted, et al. 1999). Adequate descriptors, such as barrier equivalent velocity (BEV) or equivalent barrier speed (EBS), include an explicit or implied time reference. This is further discussed in Section 2.5.

Before proceeding to our discussion of various types of collision pulses, it is necessary to assure that we have a common definition of some terms and units that we will use in that section.

2.5 COLLISION PULSE CHARACTERISTICS, TIME SIGNATURES & SIMULATION MODELS (BARRIERS, VEHICLE-TO-VEHICLE LONGITUDINAL, POLE IMPACTS, SIDE IMPACTS, UNDERRIDES)

2.5.1 Collision Pulses

We have already shown how one must evaluate the crash pulse time duration (t_{pulse} for the event, or, t_{event}), as well as the total change in velocity (ΔV) over that time duration, in order to properly evaluate forces imparted to a vehicle and to its occupants. Additionally, one must be careful to be rigorously consistent with the units in any calculation. Crash pulse characteristics (acceleration vs. time and pulse duration) will vary as the crush and rebound characteristics of the impact targets change, and this is intuitively obvious as shown in Fig. 2.16, a visually intuitive contrast between vehicle-barrier and vehicle-vehicle collision types. Let us now examine specific time and acceleration parameters, and see how they vary among collision types.

2.5.2 Impact Velocity Equivalences

A simplified barrier collision consists of a vehicle impacting a barrier, with no deformation to the barrier, and all of the

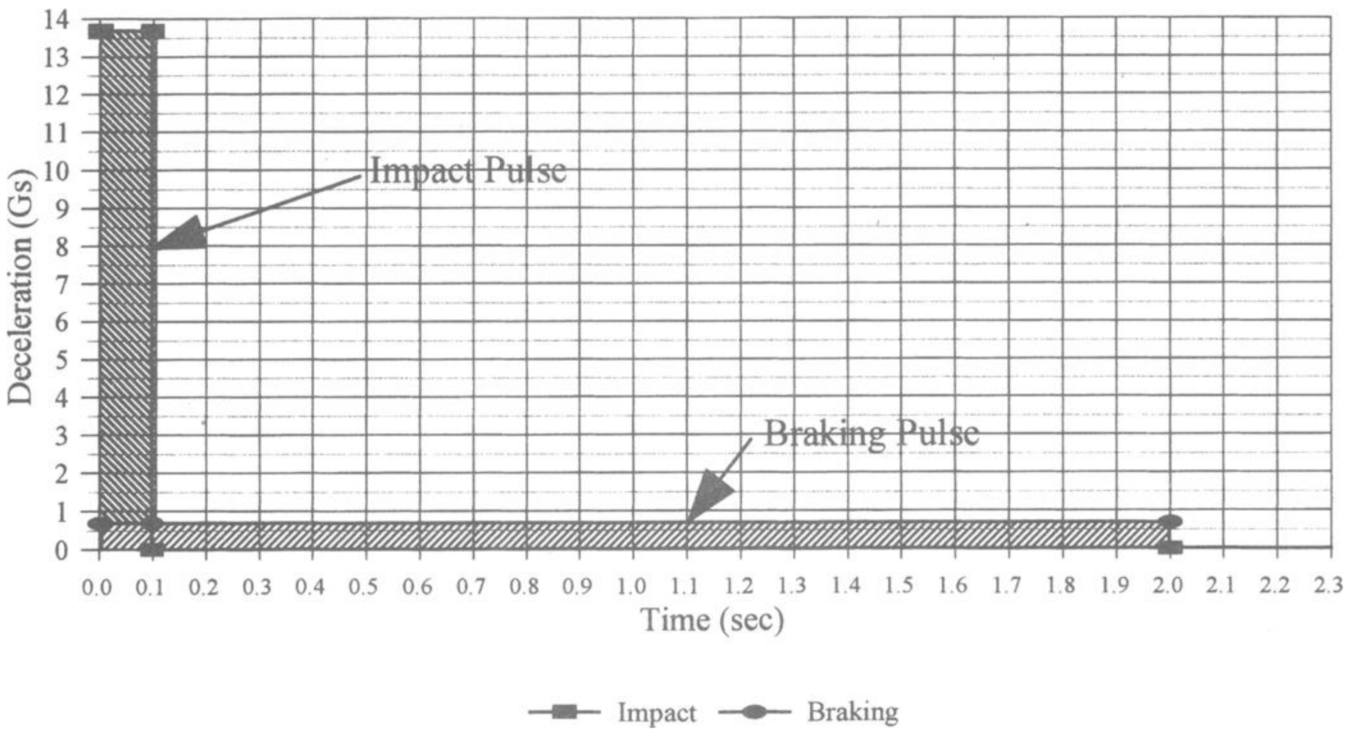


FIG. 2.15—Identical 30 mph (48.3 kph) Delta Vs are produced by different deceleration *G* levels over complementary time periods (t_{pulse}).

collision energy absorbed in the deformation of the vehicle (hence, a totally plastic collision, much like silly putty thrown against a wall), as shown in Fig. 2.17. In such a collision, we have a very straightforward velocity loss, as was shown above in the pre-rebound waveform example of Fig. 2.10. Such a velocity loss would correspond to an initial velocity decreasing to 0, as is shown in the first 110 ms of Fig. 2.18.

However, in the real world, vehicles rebound off of solid barriers. The rebound velocity usually has a value in the order of 10 to 15% of the initial approach velocity. The force that creates the rebound velocity in the 100 to 120 ms period

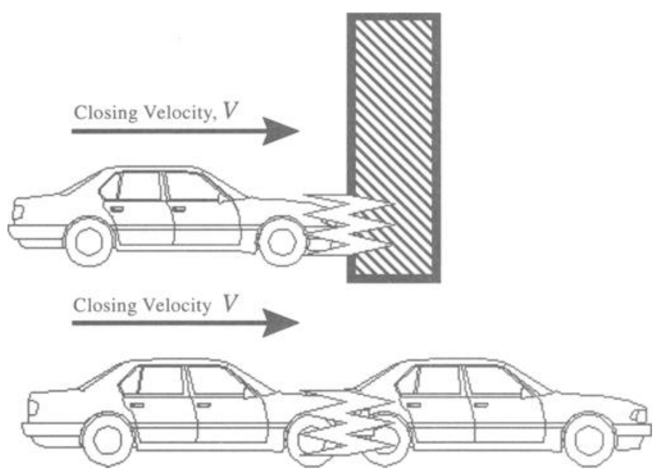


FIG. 2.16—Identical vehicles, with identical closing velocities, impacting different targets will produce different crash pulses.

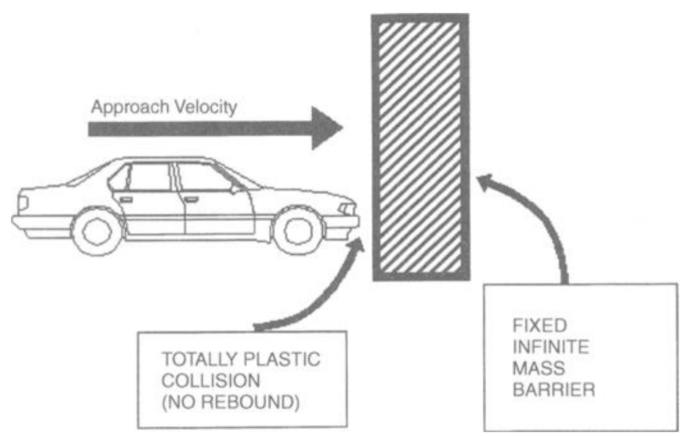


FIG. 2.17—Simplified barrier equivalent velocity (totally plastic collision, no rebound). Thus, in this case, simple Delta V = BEV = Barrier Approach Velocity.

is in the same vector direction as the initial barrier force that initially slowed the incoming vehicle in the 0 to 100 ms period. Both forces are pushing the vehicle rearward in the direction of the −X axis. Thus, the velocity changes caused by those force inputs are algebraically additive. This can be stated as:

$$\text{Total Collision Delta V (from } t = 0 \text{ to } t_{stop})$$
$$= \text{Approach Velocity} + \text{Rebound Velocity}$$

Since the Approach Velocity is also known as the Barrier Equivalent Velocity, we can substitute and state:

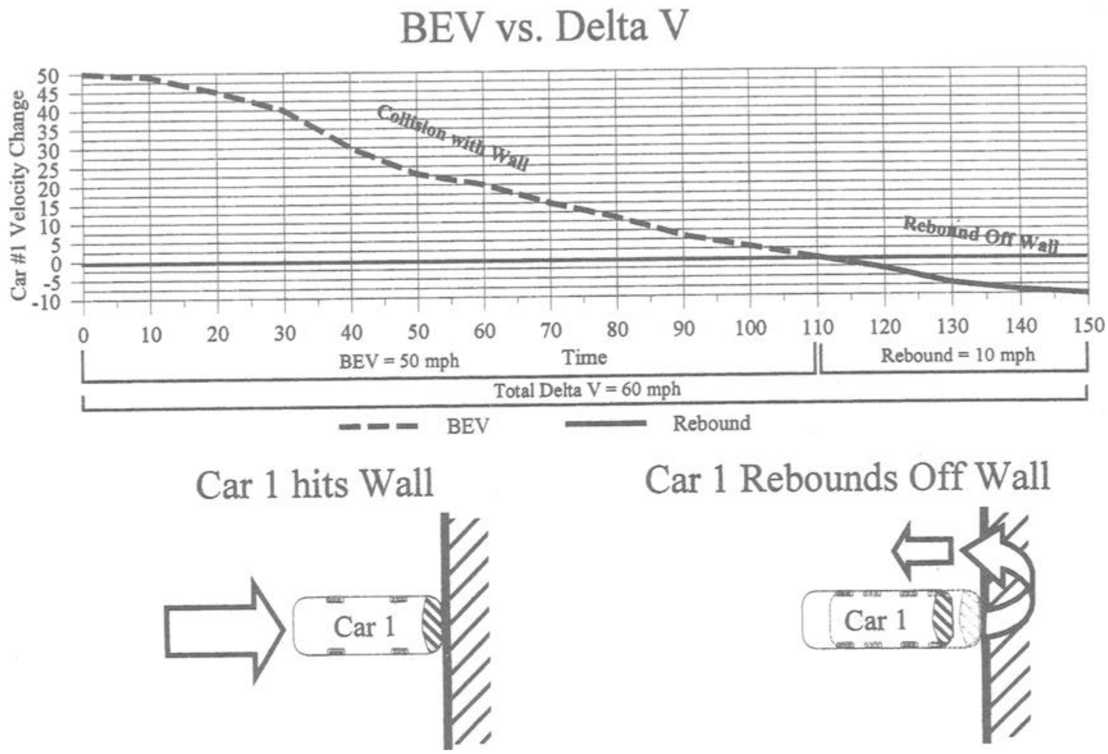


FIG. 2.18—Actual barrier equivalent velocity (includes rebound). Rebound is a vector added to the approach velocity. Thus, actual Delta V = approach velocity + rebound.

Total Collision Delta V (from $t = 0$ to t_{stop})

= Barrier Equivalent Velocity + Rebound Velocity

Collisions between an approaching vehicle and other objects produce other rebound characteristics. In general,

Barrier Equivalent Velocity

= Total Collision Delta V (from $t = 0$ to t_{stop})

− Rebound Velocity.

For example, a collision between two similar vehicles, where the *bullet vehicle* is approaching at the 'approach velocity' and the target vehicle is stopped, as shown in Fig. 2.19, generally produces a BEV of:

Barrier Equivalent Velocity = ½ Approach Velocity

We can generalize three basic collision types, and each of these may also have subsets such as normal, offset, and angled. These can be summarized as follows:

A. Vehicle-to-Barrier
   1. Full Frontal, PDOF = 0°
   2. Frontal Offset 50%, PDOF = 0°
   3. Right Side Frontal, PDOF = 30°
   4. Left Side Frontal, PDOF = 30°

B. Vehicle-to-Vehicle
   1. Full Frontal, PDOF = 0°
   2. Frontal Offset 50%, PDOF = 0°
   3. Right Side Frontal, PDOF = 30°
   4. Left Side Frontal, PDOF = 30°

C. Vehicle-to-Pole
   1. Center, Full Frontal, PDOF = 0°
   2. Frontal Offset, PDOF = 0°

Specific crash impact pulses applicable to a specific crash under investigation are generally obtained by matching, or scaling, data from known crash tests, such as we have referred to above. Known crash tests provide:

1. A time line from first test crash contact until rest, showing vehicle frame velocity, acceleration (G) at center of mass of the vehicle, acceleration (G) forces at occupant positions, and acceleration (G) at all crash sensor positions.
2. A time line from first contact until rest, for safety equipment operation signals (such as sensor closures, algorithm enable, squib electrical deployment, etc.).
3. A vehicle object displacement map versus time line from first contact until rest.
4. Manikin[12] stress calculations (Gs and/or forces) versus time from first contact until rest.
5. Manikin movement(s) with respect to the fixed (SAE J211, SAE J670e) axes of the test vehicle versus time from first contact until rest.

[12] Test Manikin and Anthropomorphic Test Device (ATD) are formal names a for a human test surrogate. These devices are also commonly called crash dummies or test dummies. A fine history of these devices is available online from First Technology Safety Systems, (First Technology 2000).

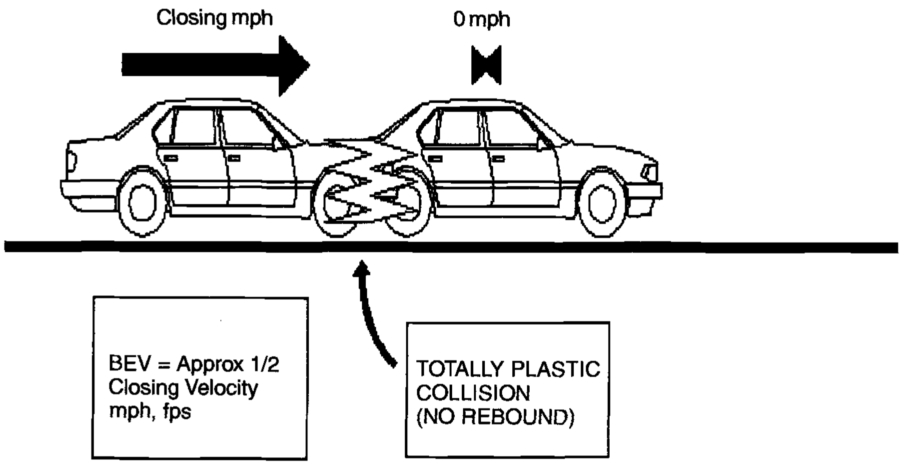


FIG. 2.19—Simplified vehicle-to-vehicle collision (bullet into target) showing that for a totally plastic collision between two similar vehicles, the accumulated collision force (energy) is distributed equally, and the resulting bullet BEV is approximately one-half the closing velocity.

Using these basic physical and mathematical relationships and standardized parameter descriptors, we can now apply them in our descriptions of vehicle collisions, which will allow us to analyze saved vehicle crash data and potentially reconstruct certain parameters of the crash.

2.6 NUMBERING SYSTEMS, COMMON UNITS AND CONVERSION FACTORS

2.6.1 Numbering Systems

One of the major barriers to understanding computer-based data presentations, such as those taken from vehicle network ECUs, is lack of familiarity with the various numbering systems used to represent the electrically stored data. Digital data (DTCs and parameters) are always transmitted around a vehicle network as serial binary data. The value of such binary data is represented using sequential high or low voltage levels to indicate the value of a binary data bit (1 or 0). For reasons of economy and order, computer programmers group the serial data into eight-bit units called bytes, and allow each half-byte (4 bits)[13] to have one of 16 values according to the *hexadecimal* numbering convention. When taken together as a byte, these eight-bit units can represent any decimal integer from 0 to 255, and there are several alternate coding schemes. Since our source data will be in hexadecimal format, it is our objective to be able to interpret the hexadecimal form of data, so, let us review this method of expressing numbers and data.

2.6.2 Decimal vs. Hexadecimal Numbering Systems

Typically, we first learn the decimal system because we can count our ten fingers. The decimal system is said to be a "base 10" system because it is based on counting ten digits (fingers). In that system, there are ten counting units, actually identified as 0 to 9, after which there is a carry to the next higher position (the tens position). Thus, the decimal number ten (10) is actually a carry of a 1 in the 10's column and no additional unit counts. We will refer to the decimal system as "the conventional system."

The hexadecimal numbering convention (base 16) is universally used as a shorthand way to represent binary computer data because that is the most efficient way to represent binary computer output with no intermediate translations. If the computer output is intended to be numeric, the eight-bit byte could take on 256 different patterns and, therefore, could stand for 256 different numbers (0 to 255 decimal).

The hexadecimal shorthand takes that each eight-bit byte four bits at a time. Each half-byte, having four bits, can have 16 different number states (0 to 15 decimal). There is a defined convention for assigning each number state a unique character. That convention is to assign the characters 0 to 9, respectively, to the lowest ten hexadecimal states in numerical order and to assign the characters A to F to the remaining six hexadecimal states. Thus, for each hexadecimal digit, the four-bit nibble correlation from hexadecimal representation to decimal number states is as follows: hex 0 to 9 = decimal 0 to 9, A (hex) = 10 (decimal), $B = 11$, $C = 12$, $D = 13$, $E = 14$, and $F = 15$. Hexadecimal numbers are typically represented with the dollar sign prefix, e.g., $21 (= 33 decimal), to distinguish that number from 21 decimal.

To illustrate how the three different base systems relate to one another, Table 2.1 shows the first 46 (0 to 45) numeric values are side by side expressed as hexadecimal, binary, and decimal numbers, respectively. From this comparison, we can see that all the numbering schemes start with 0, just as in the conventional system, and a base count, i.e., a count equal to the number system's base, forces a carry-over to the next position to the left: at the second count in the binary system, the 10th count in the conventional system, and the 16th count in the hex system.

Additional to pure numeric coding, hexadecimal encoded information can represent several other forms of informa-

[13] A half-byte is also known as a "nibble."

TABLE 2.1—Comparison of equivalent hexadecimal, binary, and decimal numbers.

Hexadecimal	Binary	Decimal	Hexadecimal	Binary	Decimal
00	0000 0000	00	17	0001 0111	23
01	0000 0001	01	18	0001 1000	24
02	0000 0010	02	19	0001 1001	25
03	0000 0011	03	1A	0001 1010	26
04	0000 0100	04	1B	0001 1011	27
05	0000 0101	05	1C	0001 1100	28
06	0000 0110	06	1D	0001 1101	29
07	0000 0111	07	1E	0001 1110	30
08	0000 1000	08	1F	0001 1111	31
09	0000 1001	09	20	0010 0000	32
0A	0000 1010	10	21	0010 0001	33
0B	0000 1011	11	22	0010 0010	34
0C	0000 1100	12	23	0010 0011	35
0D	0000 1101	13	24	0010 0100	36
0E	0000 1110	14	25	0010 0101	37
0F	0000 1111	15	26	0010 0110	38
10	0001 0000	16	27	0010 0111	39
11	0001 0001	17	28	0010 1000	40
12	0001 0010	18	29	0010 1001	41
13	0001 0011	19	2A	0010 1010	42
14	0001 0100	20	2B	0010 1011	43
15	0001 0101	21	2C	0010 1100	44
16	0001 0110	22	2D	0010 1101	45

tion. These information types are most completely defined as "SLOT" information which is defined by the Society of Automotive Engineers (SAE) recommended practice J2178-2 to be Scaling, Limit, Offset and Transfer Function specifications that allow encoded engineering data to be interpreted into Engineering Units such as PSI, seconds, volts, amps, *G*s, etc. (SAE 1997b). Understanding that data can actually exist across several bytes, ten potential data types are defined in SAE J2178-2:

1. Multiple Parameter Packet (byte), where more than one condition or value is contained within a hexadecimal value (or byte).
2. Bit Mapped Without Mask, where each bit of an eight bit byte represents a predefined binary condition (e.g., on/off), dependent upon the position of that byte within the byte.
3. Bit Mapped With Mask Byte, where each bit of an eight bit byte represents a binary condition (e.g., on/off), dependent upon the position of that byte within the byte, and the data byte is followed by a definition (mask) byte indicating which data bits of the information byte are valid.
4. Unsigned Numeric, where the decimal interpreted value represents an engineering unit, depending upon a value resolution specification (e.g., each count = 0.5 mph).
5. 2^s Complement Signed Numeric, where the numeric value of the lower seven bits (Bits 0 to 6) represents a value, whose sign depends on the MSB (most significant bit, Bit 7). If the MSB is "1" the value is negative, and if the MSB is "0" the value is positive. Similar to 4, the decimal interpreted value represents an engineering unit, depending upon a value resolution specification (e.g., each count = 0.5 mph).
6. State Encoded, where the data can represent a coding that stands for a condition or state of a parameter, system or a device. States can include day of the week, day of the month, transmission gear engaged, operational mode, etc.
7. ASCII Encoded, where the value of the byte indicates an ASCII character. ASCII encoded bytes are the type of bytes sent by computers via parallel ports to printers to print text documents.
8. Binary Coded Decimal, where each eight-bit byte is split into two four-bit halves (called nibbles) and the numeric value of each nibble represents a decimal digit.
9. Signed Floating Point, where a combination of bytes represent a sign, exponent, and fractional part of an engineering unit, depending upon a value resolution specification.
10. Multiple Frame, Single Parameter Format, where long parameters are encoded across multiple serial data frames.

Many of these SLOT encoding techniques are explained and illustrated in the ECU hexadecimal data interpretations shown in the six case studies of Chapter 6.

2.6.3 Common Units and Conversions

The velocity of a mass moving between any two points can be stated as displacement divided by time or,

$$V = \frac{\text{displacement}}{\text{time}}$$

This is typically stated as mph or kph, but could also be stated as ft/s, m/s, in/ms, m/ms, cm/ms, etc. Sometimes it is equally useful to know the reciprocal time/distance at a particular velocity. Table 2.2 shows an abbreviated set of inter-unit velocity conversions for (displacement/time), as well as its reciprocal (time/distance), with 1 mph and 1 kph resolution (1 to10 mph/kph). A complete table of inter-unit velocity conversions for (displacement/time), as well as its reciprocal (time/distance), with 1 mph and 1 kph resolution (1 to 100 mph/kph) is included in Appendix A.2.1, Conversion Factors by Unit MPH and A.2.2, Conversion Factors by Unit KPH.

TABLE 2.2—Abbreviated set of inter-unit velocity conversions for (displacement/time), as well as its reciprocal (Time/Distance), with 1 mph and kph resolution (1 to 10 mph/kph). Conversions between Metric and English Units.

mph	ft/s	ft/ms	ms/ft	ms/in	in/ms	kph	m/s	m/ms	ms/m	ms/cm	cm/ms
1	1.4667	0.0015	681.8182	56.8182	0.0176	1.6094	0.4471	0.0004	2236.8585	22.3686	0.0447
2	2.9333	0.0029	340.9091	28.4091	0.0352	3.2188	0.8941	0.0009	1118.4292	11.1843	0.0894
3	4.4000	0.0044	227.2727	18.9394	0.0528	4.8282	1.3412	0.0013	745.6195	7.4562	0.1341
4	5.8667	0.0059	170.4545	14.2045	0.0704	6.4376	1.7882	0.0018	559.2146	5.5921	0.1788
5	7.3333	0.0073	136.3636	11.3636	0.0880	8.0470	2.2353	0.0022	447.3717	4.4737	0.2235
6	8.8000	0.0088	113.6364	9.4697	0.1056	9.6564	2.6823	0.0027	372.8097	3.7281	0.2682
7	10.2667	0.0103	97.4026	8.1169	0.1232	11.2658	3.1294	0.0031	319.5512	3.1955	0.3129
8	11.7333	0.0117	85.2273	7.1023	0.1408	12.8752	3.5764	0.0036	279.6073	2.7961	0.3576
9	13.2000	0.0132	75.7576	6.3131	0.1584	14.4846	4.0235	0.0040	248.5398	2.4854	0.4024
10	14.6667	0.0147	68.1818	5.6818	0.1760	16.0940	4.4706	0.0045	223.6858	2.2369	0.4471
kph	**m/s**	**m/ms**	**ms/m**	**ms/cm**	**cm/ms**	**mph**	**ft/sec**	**ft/ms**	**ms/ft**	**ms/in**	**in/ms**
1	0.2778	0.0003	3600.0000	36.0000	0.0278	0.6214	0.9113	0.0009	1097.2998	91.4416	0.0109
2	0.5556	0.0006	1800.0000	18.0000	0.0556	1.2427	1.8227	0.0018	548.6499	45.7208	0.0219
3	0.8333	0.0008	1200.0000	12.0000	0.0833	1.8641	2.7340	0.0027	365.7666	30.4805	0.0328
4	1.1111	0.0011	900.0000	9.0000	0.1111	2.4854	3.6453	0.0036	274.3249	22.8604	0.0437
5	1.3889	0.0014	720.0000	7.2000	0.1389	3.1068	4.5566	0.0046	219.4600	18.2883	0.0547
6	1.6667	0.0017	600.0000	6.0000	0.1667	3.7282	5.4680	0.0055	182.8833	15.2403	0.0656
7	1.9444	0.0019	514.2857	5.1429	0.1944	4.3495	6.3793	0.0064	156.7571	13.0631	0.0766
8	2.2222	0.0022	450.0000	4.5000	0.2222	4.9709	7.2906	0.0073	137.1625	11.4302	0.0875
9	2.5000	0.0025	400.0000	4.0000	0.2500	5.5922	8.2020	0.0082	121.9222	10.1602	0.0984
10	2.7778	0.0028	360.0000	3.6000	0.2778	6.2136	9.1133	0.0091	109.7300	9.1442	0.1094

TABLE 2.3—Tables of *Gs* for English and Metric.

Gs	ft/sec²	in/sec²	m/s²	cm/s²
1	32.17	386.04	9.81	98.10
2	64.34	772.08	19.62	196.20
3	96.51	1158.12	29.43	294.30
4	128.68	1544.16	39.24	392.40
5	160.85	1930.20	49.05	490.50
6	193.02	2316.24	58.86	588.60
7	225.19	2702.28	68.67	686.70
8	257.36	3088.32	78.48	784.80
9	289.53	3474.36	88.29	882.90
10	321.70	3860.40	98.10	981.00
11	353.87	4246.44	107.91	1079.10
12	386.04	4632.48	117.72	1177.20
13	418.21	5018.52	127.53	1275.30
14	450.38	5404.56	137.34	1373.40
15	482.55	5790.60	147.15	1471.50
16	514.72	6176.64	156.96	1569.60
17	546.89	6562.68	166.77	1667.70
18	579.06	6948.72	176.58	1765.80
19	611.23	7334.76	186.39	1863.90
20	643.40	7720.80	196.20	1962.00
21	675.57	8106.84	206.01	2060.10
22	707.74	8492.88	215.82	2158.20
23	739.91	8878.92	225.63	2256.30
24	772.08	9264.96	235.44	2354.40
25	804.25	9651.00	245.25	2452.50

When one deals with forces and accelerations, acceleration is often expressed in terms of *G*, or multiples of *G*, where *G* is the unit symbol that stands for the acceleration due to gravity of a free-falling object near the Earth's surface which is 32.17 ft/s^2 (9.81 m/s^2).[14] *G* is a universal unit used to describe vehicle acceleration or deceleration magnitudes. Table 2.3 shows inter-unit conversions for acceleration with 1 *G* resolution and a precision extended to two decimal places.

[14] The constant *G* is usually rounded to a single decimal place precision, 32.2 ft/s^2 or 9.8 m/s^2, and those rounded values are used in the balance of calculations in this book (except for Table 2.3).

A Review of Air Bag System Architecture, Components, and Stored Data[1]

3

3.1 THE PERFORMANCE OF AIR BAGS AS A SAFETY DEVICE

IN ITS REPORT OF JANUARY 2000, NHTSA Special Crash Investigations Unit (SCI) estimates that for the usage period from 1986 through January 1, 2000, air bags have saved 4301 driver lives and 764 passenger lives (NHTSA 2000). Along with this benefit, NHTSA/SCI estimates a subset of incidents where injuries, and even fatalities, were caused by air bags. NHTSA data show that there were 150 fatalities attributed to air bags in this period, broken down as 57 driver, 6 adult passenger, and 87 child fatalities. Figure 3.1 summarizes these data and provides a risk/benefit perspective showing that air bags are generally a positive safety measure.

Passenger vehicle air bag systems are designed so that the folded fabric envelope should be substantially fully inflated before the occupant contacts it in a crash ride-down. As such, the inflated envelope forms a benign air pillow, or cushion, hence the term "air bag," and this air bag lengthens the occupant's deceleration ride-down time in a collision, thus reducing the occupant's peak stress. An air bag serves to assist and improve the safety characteristics of seat belt equipped vehicles and is primarily intended as a supplemental safety device. However, given the statistics above, there are sometimes questions, after a crash, as to whether certain injuries are air bag induced versus crash induced (Kress et al. undated), and whether seat belts were used, brakes were applied, etc. Such questions arise when one or more of the following conditions can be identified and confirmed:

1. *Delayed deployment*—allowing the occupant to hit the wheel/dash before the air bag has deployed as an air cushion.
2. *Punchout*—allowing the occupant to be adjacent to the air bag module cover so as to be struck by the cover.
3. *Membrane loading*—allowing the occupant to be positioned just back from the air bag module cover so as to be thrown about the passenger compartment by the force of the inflating envelope.
4. *Bag slap*—allowing the occupant to be at a distance from the air bag module cover so as to be struck by the air bag fabric at a high velocity.
5. Leading edge velocity to be unreasonably high at throw distances corresponding to expected occupant positions, allowing the envelope to cause bag slap injuries in expected occupant positions (as contrasted to out of position (OOP) conditions).
6. Failing to make a no-fire decision, when the system could determine that the occupant was belted and the vehicle velocity was low enough so that there was more likelihood of an injury from the deploying air bag than from riding down the impact, while belted, without deploying the air bag.
7. Failing to deploy, when the vehicle velocity was high enough so that there was unquestioned benefit from deploying the air bag, compared to riding down the impact, with and/or without seat belts.
8. *Premature Deployment*—when crash conditions are absent or under any reasonable threshold.

Many answers can often be found with a forensic investigation of markings and artifacts in the crash vehicle, EEPROM/flash memory data in air bag and ABS computers, and an investigation of the dynamic characteristics of the air bag itself.

3.2 AIR BAG SUPPLEMENTAL RESTRAINTS, CRASH PULSE INPUT VECTORS, AND DESIGN AXIS SENSITIVITY

All current air bag systems include a driver-side air bag[2] and most now also include a passenger-side air bag. Some also contain side and head air bags as well.[3] Air bag systems are generically referred to as supplemental restraint systems (SRS),[4] because these devices are generally designed to act in addition to basic manual seat belts and/or automatic seat belts. Devices that operate without manual effort or participation of the occupant are also collectively designated as

[1]Portions of this chapter may be similar to, or reprinted from, Chapter 2, "Air Bag System Analysis," *Forensic Accident Investigation: Motor Vehicles, Vol. 2*, with the express permission of the publisher, Matthew Bender & Co, Inc., a part of LEXIS-NEXIS.

[2]Its presence in the vehicle will usually be accompanied with an explicit notice on the steering wheel or instrument panel referring to "air bag," "SRS," or some variant nomenclature.

[3]Additionally, under the umbrella of "supplemental restraint systems," some vehicles are equipped with crash-activated electrical seat belt tensioners, and a few convertibles contain crash-activated or roll-activated roll bars. In the belt tensioning assemblies, when they are activated, the propellant created by an explosive charge pushes a piston up a tube. A steel cable attached to that piston winds a spool that pretensions the seat belt before it sees the occupant deceleration load. The pretensioner assemblies are usually located in the lower mounting or the seat belt assembly. Automatic roll bars are deployed when certain sensors (some additional to the SRS sensors) sense potential rollover conditions.

[4]There are many acronyms used to identify various SRS systems, components, and data. These are listed in Appendix A, "Glossary of Terms and Conversion Factors Used in Vehicle Data Systems." An industry reference to SRS/air bag terms is given in SAE J1538, "Glossary of Automotive Inflatable Restraint Terms."

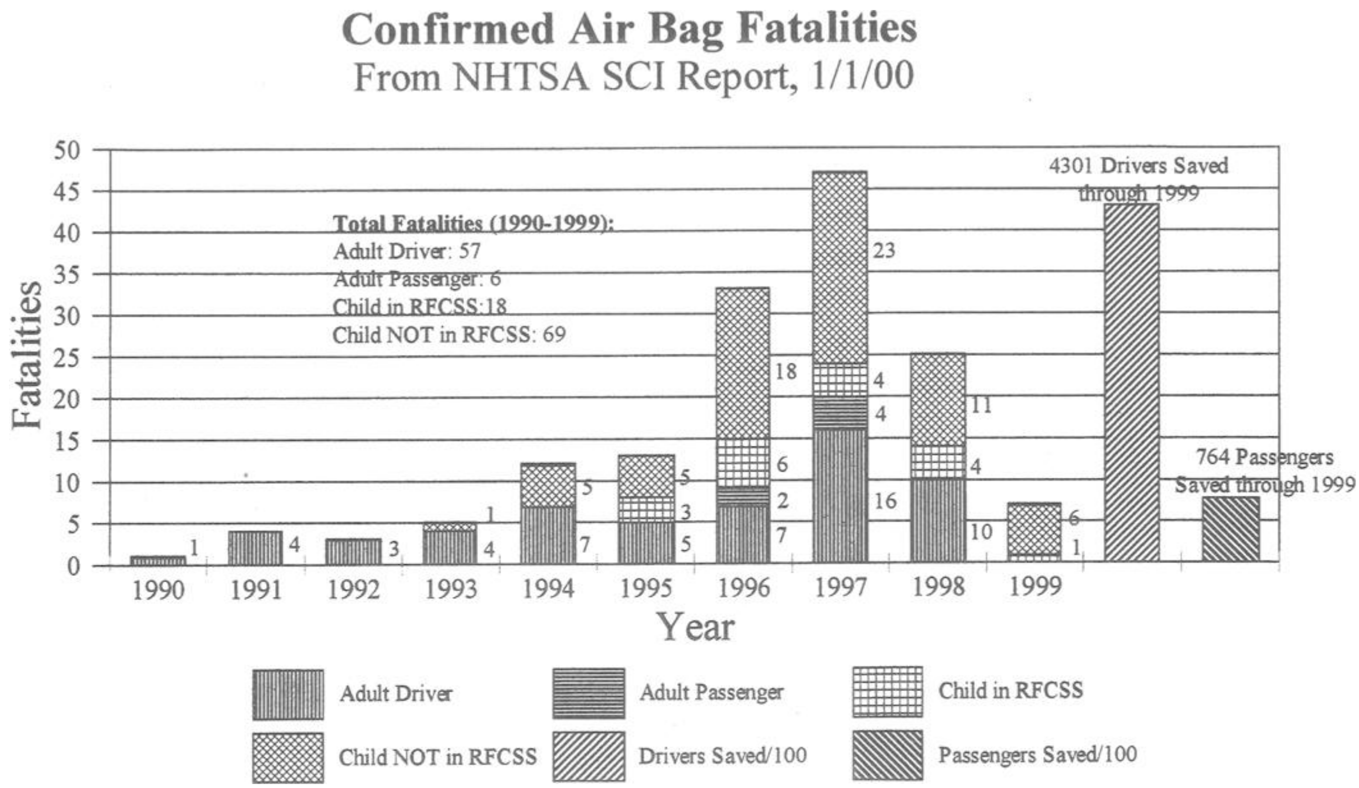


FIG. 3.1—Air bag fatalities versus lives saved from 1986 through June 1999. (Data from NHTSA occupant protection update, Fall 1999.)

"passive restraint systems."[5] This is in contrast to the standard two- and three-point "active" seat belt assembly, which requires purposeful manual buckling or closure by the occupant in order for it to work.

The driver steering wheel mounted and passenger instrument panel mounted air bag systems are designed to respond to a frontal impact measured as a crash pulse in the –X axis (longitudinal design axis), as defined by SAE J211 and SAE J670e, and discussed in Chapter 2.[6] To recap that discussion, the reference axes are shown in Fig. 3.2. Frontal barrier crashes generate pulses substantially in the −X axis, and these air bag system sensors are generally designed so that they respond to crash pulses with sufficient magnitudes included within ±30 degrees of the −X axis.

The direction of a crash pulse is known as its PDOF (principal direction of force), and the PDOF vector generally has components in the X and Y axes. If the −X component of a frontal PDOF vector has sufficient magnitude, it will cause the longitudinal sensors to respond and fire the frontal air bags.

3.3 COMPONENTS OF AIR BAG (SRS) SYSTEMS

3.3.1 Common Components

All air bag-equipped vehicles have certain common components. These consist of an electronic control unit (ECU), one or more air bag assemblies (modules), one or more sensors, and a wiring harness. In many vehicles, the air bag wiring harness is specially colored (yellow or orange) to distinguish it from the rest of the vehicle wiring. SRS system operation is usually transparent to the occupants in normal operation, except for the air bag malfunction indicator lamp (MIL) in the instrument cluster. The MIL is normally activated during key-on diagnostic checks and remains off unless a system problem is detected.

3.3.2 First Generation Air Bag Systems—Distributed Sensor Switches

Most first generation systems used a distributed sensor architecture as shown in Fig. 3.3. In this architecture, the crash impact was detected by two or more sensors. These sensor

[5]These names are obviously not the same. "Passive restraint system" reflects the NHTSA's original intent that a restraint system could be implemented that required no action on the part of the person to be protected. "Supplemental restraint system" reflects the current policy that the air bags are to be used in conjunction with, i.e., to supplement, active restraint systems such as the three-point belt restraint.

[6]Of course, side air bags are an obvious exception to this, and side air bags generally have their own sensors, oriented to their respective side axes.

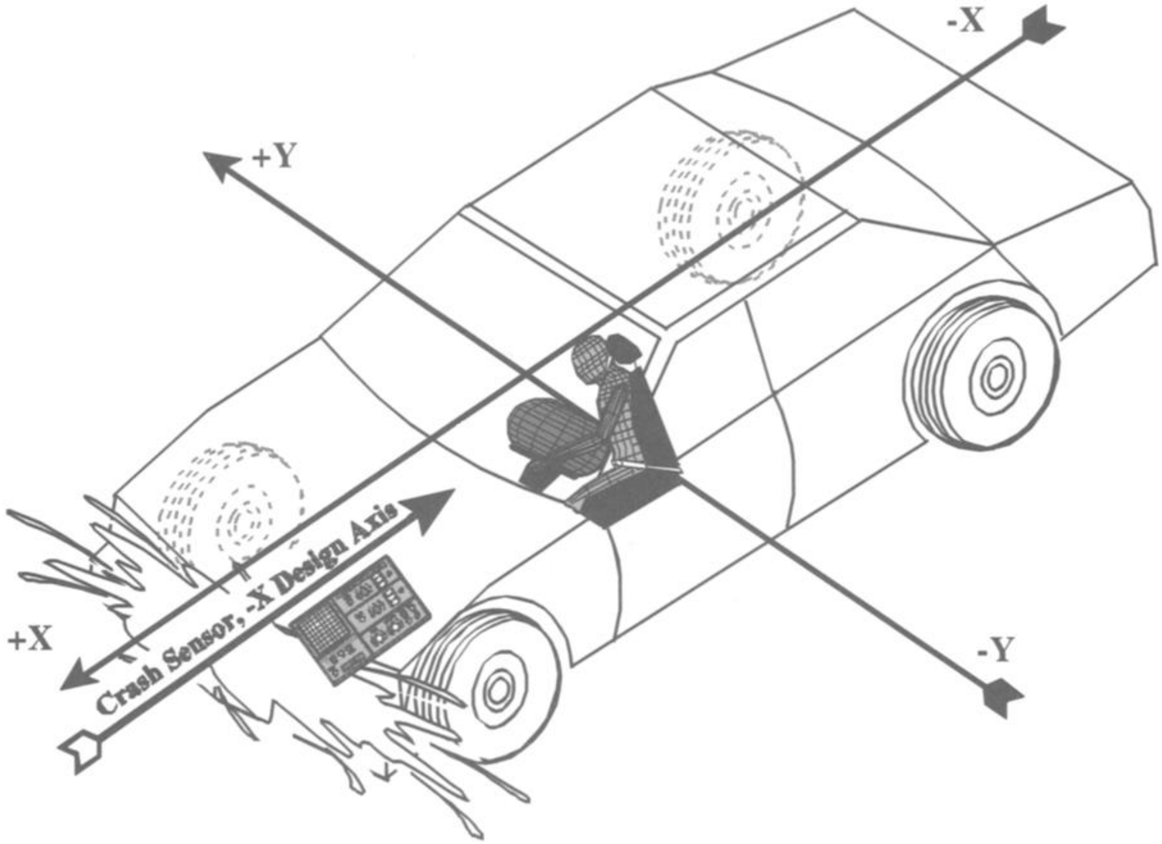


FIG. 3.2—Air bag sensor longitudinal −X design axis with planar SAE J211/J670e axis references.

assemblies consisted of a mass, inside a sealed housing, which translated inside the housing after receiving a force input over time. This translation would then close an electrical switch, completing its portion of the firing circuit. The mass was held in place against an adjustable backstop by a spring. The spring (tension) served to impart a bias threshold and a response envelope to the sensor, and these parameters were known as the sensor's calibration. Since the squib[7] is fired by an electrical pulse, these calibrated sensors (inertia switches) were used to close a circuit which provided the electrical pulse to fire the squib circuit.

In order to prevent inadvertent actuation, two sensors having different calibrations were required to be closed simultaneously to actually provide the electrical pulse to fire the squib circuit. This was accomplished by placing the two differently calibrated sensors in a series circuit. The forward sensors, known as discriminating or crash sensors, were usually positioned in the crush zone in the front of the vehicle and calibrated for switch closure in response to a relatively high-level, short-duration deceleration. The rearward sensor, known as an arming or safing sensor, was positioned in the occupant compartment and was calibrated for a switch closure response to a relatively low in magnitude, longer-duration deceleration.

The series circuit is shown in Fig. 3.4. The series circuit is the logical equivalent of an AND function, meaning that two different conditions are true at the same time. Since two should-fire calibrations were true at the same time, the ANDed condition was known as *overlap*. In other words, the arming sensor AND the (left front or right front) discriminating sensor had to be closed simultaneously (closures overlapped in time) to close the series circuit to fire the squib. Some early diagnostic monitoring SRS ECUs recorded the sensor closure sequence, sensor closure timing, and sensor overlap time and duration in the MPU EEPROM.

As shown in the schematic of Fig. 3.4, squib fire is enabled only when a combination of at least one crash/discriminating sensor[8] and the arming sensor become concurrently closed to complete the series firing circuit.

[7]The term *squib* is borrowed from the military name for an electrically fired explosive device, and also a device that burns relatively slowly, rather than exploding, or a priming device that is used to ignite a secondary explosive. In air bag technology, squib has come to be used as the general name for the electrically ignited device that triggers air bag envelope inflation. In conventional inflaters, the squib ignites sodium azide pellets in a metal capsule, which produces nitrogen gas for envelope inflation. In newer *hybrid* inflaters, the squib opens a seal that releases high pressure stored inert gas for envelope inflation. The reader may wish to refer to MIL-S-17923B for additional background on squibs.

[8]The crash/discriminating sensors are in a parallel electrical circuit, providing a logical OR function. Thus, a closure of either crash sensor switch provides an equivalent electrical path towards firing the air bag. The parallel circuit OR function is shown in Fig. 3.4.

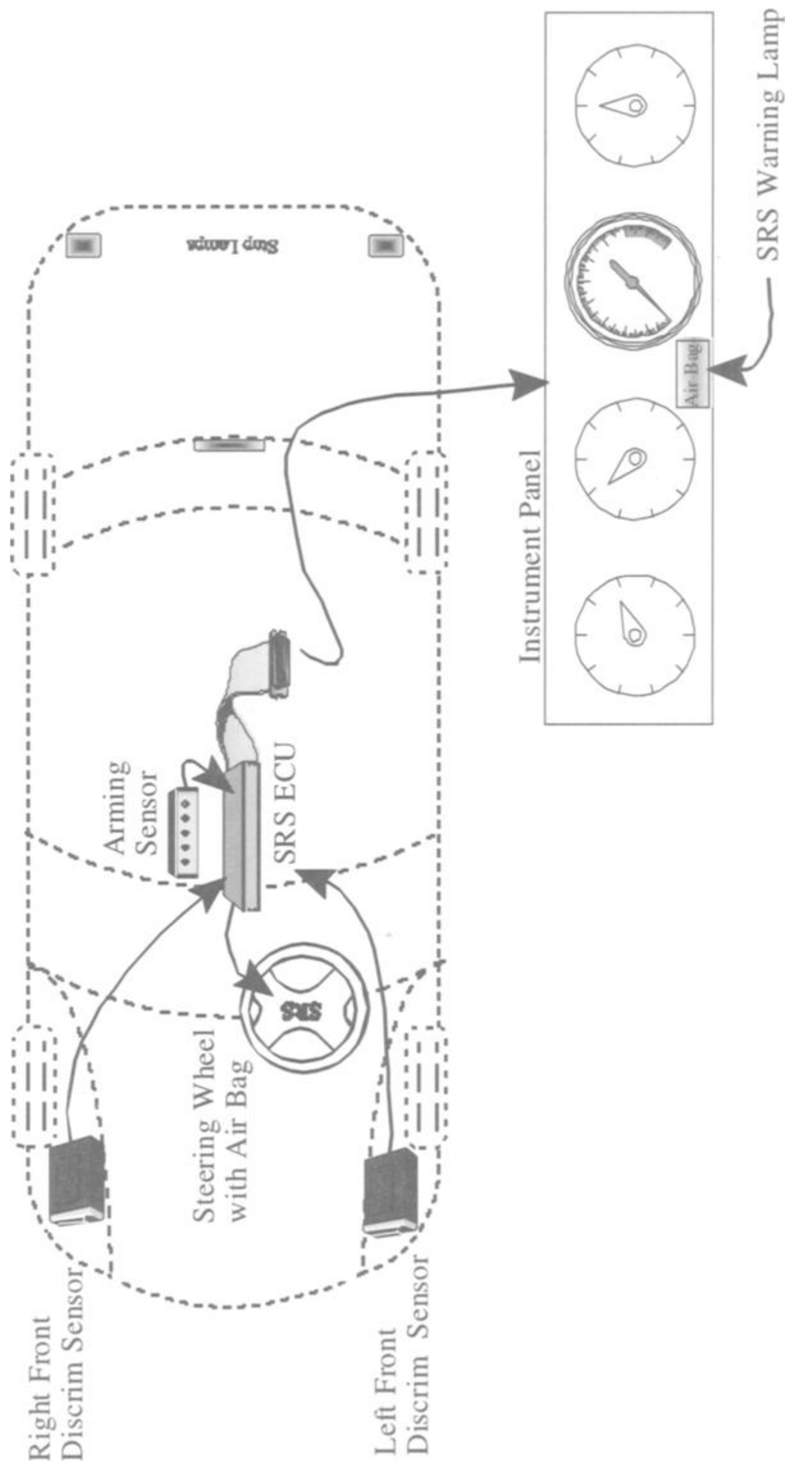


FIG. 3.3—SRS (air bag) system with distributed sensor architecture.

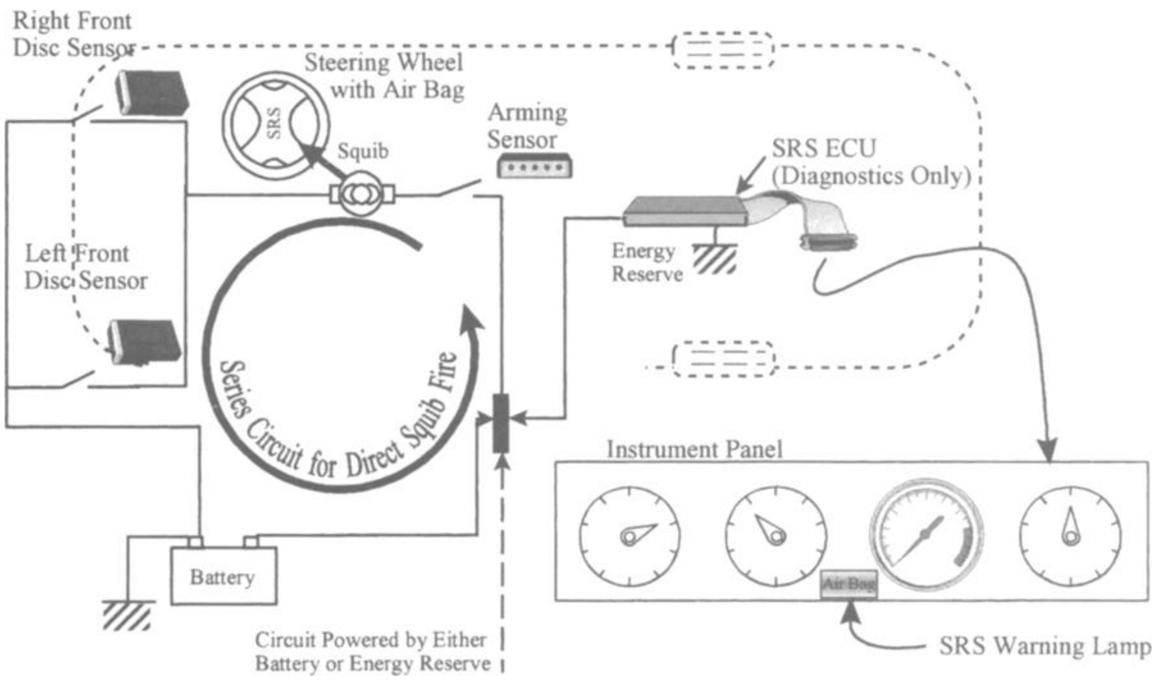


FIG. 3.4—First generation system: squib fired by series circuit sensor switches.

The requirement for an overlapped response from two differently calibrated accelerometer switches was used to minimize inadvertent deployments from odd localized shocks, such as undercarriage debris or animal impacts.

In first generation systems, the ECU had two functions—diagnostics and energy reserve. Diagnostics were required to alert the operator of any detected malfunction condition that would affect the operation of the air bag protection system. The usual alert was the air bag lamp in the instrument cluster. Formally this lamp is called the air bag malfunction indicator lamp (MIL). A second function of the ECU was to provide the energy reserve sufficient to fire the air bags even if the battery feed to the system was severed in the crash. This was accomplished with electrical charge storage capacitors, usually within the ECU case.

Figure 3.4 also shows that the air bag series circuit can be powered from either the vehicle battery or the ECU energy reserve (charged capacitor). This was to prevent nondeployments when the battery cables were severed early in a crash.

The earliest technique to read stored error codes utilized the air bag MIL to communicate "blink codes" representing the numeric identification of the DTC. This was accomplished by allowing the technician to electrically request a diagnostic mode, and then count the lamp on/off blink patterns on the air bag MIL in the instrument cluster. The blink patterns had different time separations for intracode digits and for intercode (DTC) spacers. Thus, single and multiple DTCs could be determined. The MIL blink code diagnostics concept, with example blink code patterns, is shown in Fig. 3.5.

3.3.3 Intermediate Generation Air Bag Systems—Distributed Sensor Switches with Intra-ECU Transistor Fire Control

Intermediate systems incorporated additional firing logic in the ECU. These systems retained external sensor switches, but, because firing logic was added, moved the firing control and firing switches into the ECU. Internal to the ECU, logical conditions could be tested, and firing pulses lengthened for optimum performance. The firing circuit consisted of power transistors, which were turned on after the firing logic conditions had been satisfied. A schematic of this form of system architecture is shown in Fig. 3.6. As with first generation systems, the air bag firing circuit could be powered from either the vehicle battery or the ECU energy reserve, thus preserving the redundant energy source for deployment. Intermediate generation systems are sometimes called hybrid systems but this term should not be confused with hybrid inflators as defined above.

3.3.4 Second Generation Air Bag Systems—Integrated Continuous Accelerometer Sensors

Second generation systems use an integrated sensor architecture, which combines all crash pulse sensing within the SRS ECU, as shown in Fig. 3.7. The ECU affixed to the vehicle at a central location so as to detect the overall crash pulse. The crash pulse is detected with two types of sensors: the first is usually an electromechanical switch to perform the arming/safing function (just as in earlier systems), and the second is an integrated-circuit accelerometer, which generates an electrical output signal proportional to the acceleration it senses at each moment in time. That accelerometer signal is monitored by an internal microprocessor, which compares the time signature of the current acceleration pulse (or its velocity integral) with calibration examples from known crash tests.[9] This system still uses an MIL to alert the

[9]The calibration crash threshold data are stored within the ECU in PROM, EEPROM or flash memory components. If the calibration crash threshold data are saved in EEPROM or flash memory, the designer has a way to update the calibration while the ECU is in the vehicle without hardware replacement.

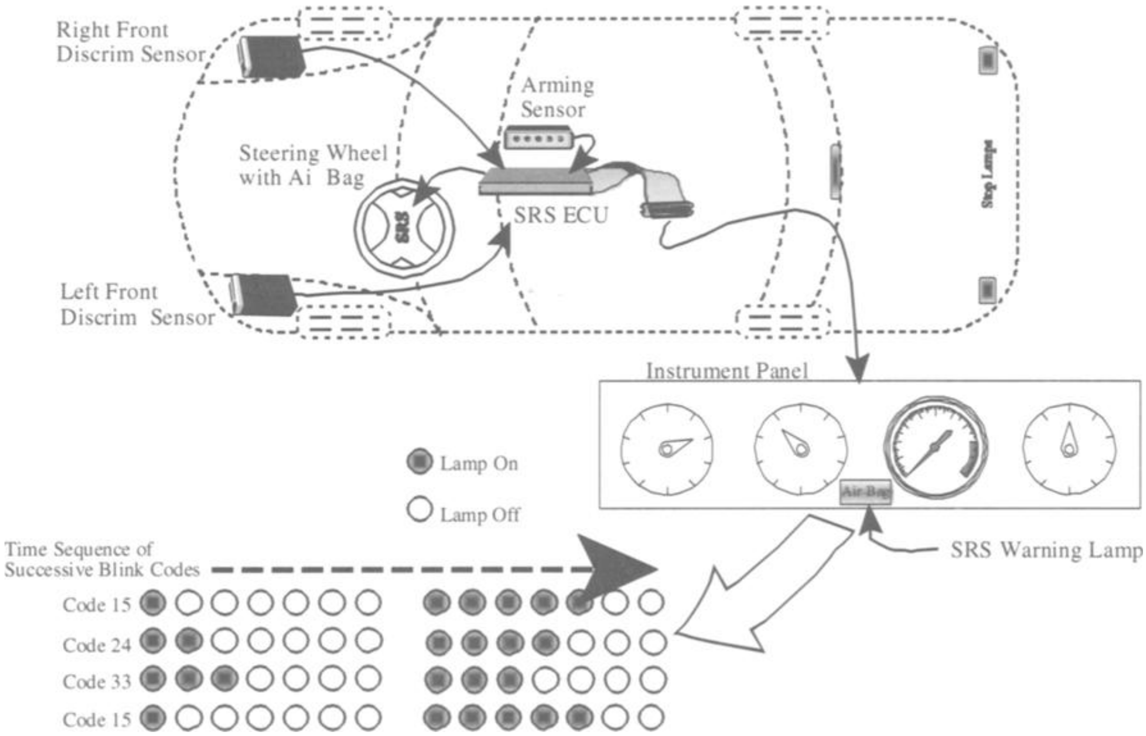


FIG. 3.5—Lamp blink code diagnostics in first generation SRS ECUs. This earliest technique to read stored error codes utilized the air bag MIL to communicate "blink codes" representing the numeric identification of the DTC. This was accomplished by counting the time sequence of the lamp on/off blink pattern(s) on the air bag MIL in the instrument cluster.

driver to malfunctions, and its firing circuit consists of power transistors, which are turned on after the firing logic conditions and thresholds have been satisfied. A more detailed schematic of this form of system architecture is shown in Fig. 3.8. As with first generation systems, the air bag firing circuit could be powered from the vehicle battery or the ECU energy reserve, thus preserving the redundant energy source for deployment. Additionally, these systems can have a second energy reserve to assure that crash snapshot (freeze frame) data is saved, even if battery power is lost in the crash.

3.3.5 Third Generation Air Bag Systems—Adaptive Feedback Controlled Deployments

Third generation systems continue to use an integrated sensor architecture, and combine external feedback to further refine and control air bag deployments. Additionally, there may now be several air bags distributed within the vehicle. Such systems are called "smart air bags," and these are not restricted to the U.S. domestic market. Newer worldwide examples include:

- 2001 GME Corsa, which includes seat cushion sensing to detect the presence of a child seat in the right front passenger position, (AEI 2000b).
- 2001 Ford Europe Mondeo, which includes adaptive dual stage air bags deployed by a system that analyzes crash severity, driver position, and passenger seat occupancy, (AEI 2000a).
- 2001 XK Jaguar, which uses ultrasonic-based occupant position sensing and traditionally sensed seat track and weight sensors for three stage control of deployment, (Birch 2000).

3.3.6 Sensors

All air bag systems are designed to operate when they detect a high enough vehicle velocity change over a short enough time period to cause a deceleration pulse ($-X$ axis acceleration, as shown in Fig. 3.2), which exceeds thresholds known from test crashes to have undesirable occupant injury potential.[10] The response to frontal crashes is generally specified to be limited to PDOFs within ± 30 degrees of the longitudinal center line (X axis).

Vehicle deceleration (acceleration imparted to a sensing device) is detected by monitoring the displacement of a sensing mass with respect to its housing. In vehicle sensing electronics, the sensor housing is usually sealed from dust and water, and is firmly mounted to the vehicle frame.

3.3.6.1 Electromechanical Discriminating Sensors

In first generation systems, the discriminating sensors consist of a mass that moves relative to its housing in response

[10]Note that rear-end impacts will cause the target vehicle to experience $+X$ axis acceleration, and this can be injurious (e.g., whiplash), but frontal air bag sensors are not designed to respond to $+X$ axis acceleration pulses. Axis conventions are discussed in Chapter 2.1 and crash pulses are discussed in Chapter 2.4 and 2.5.

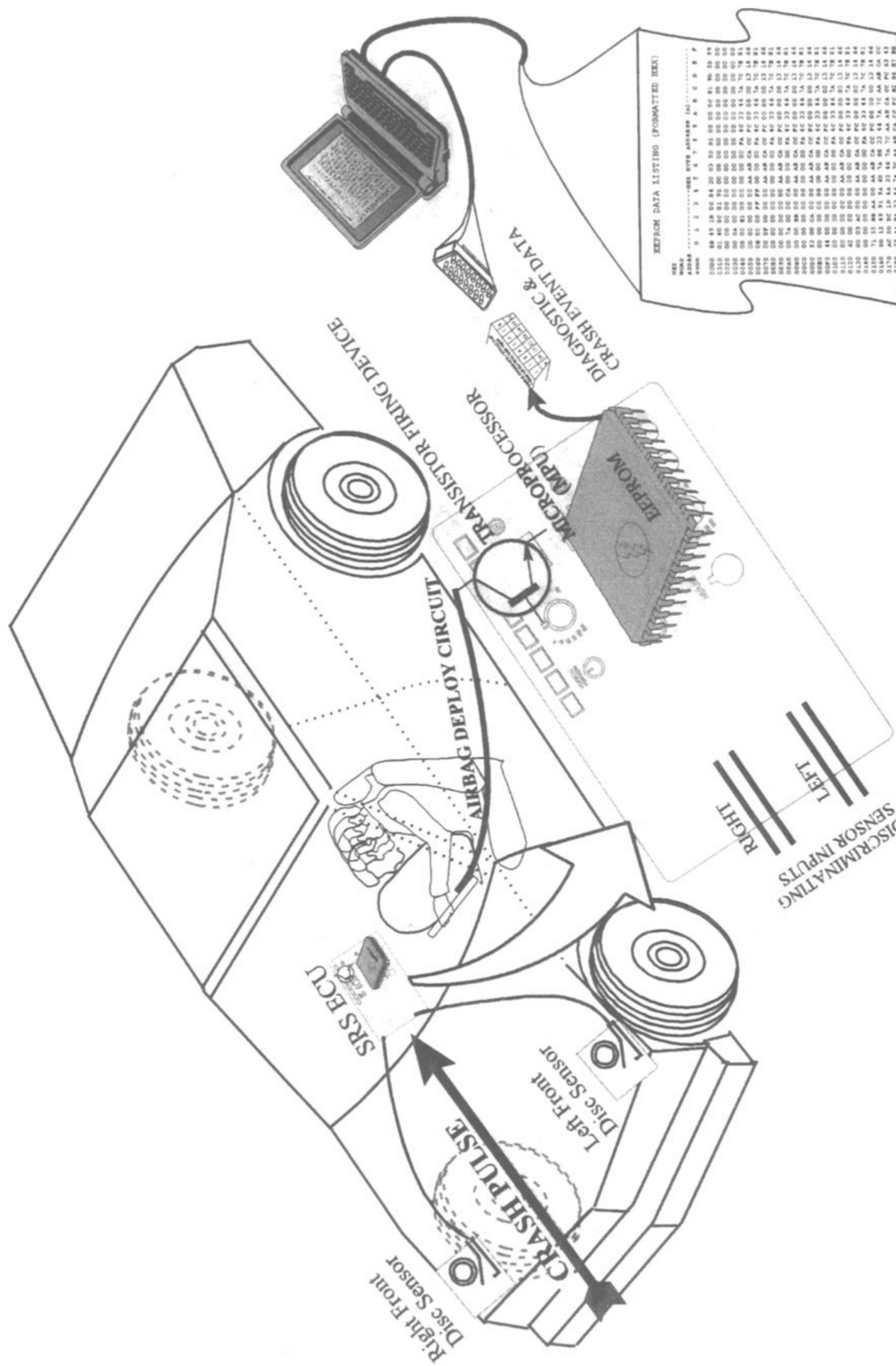


FIG. 3.6—Hybrid SRS ECU architecture: Using external sensor switches to detect a crash and internal transistor switches to fire the air bag squibs.

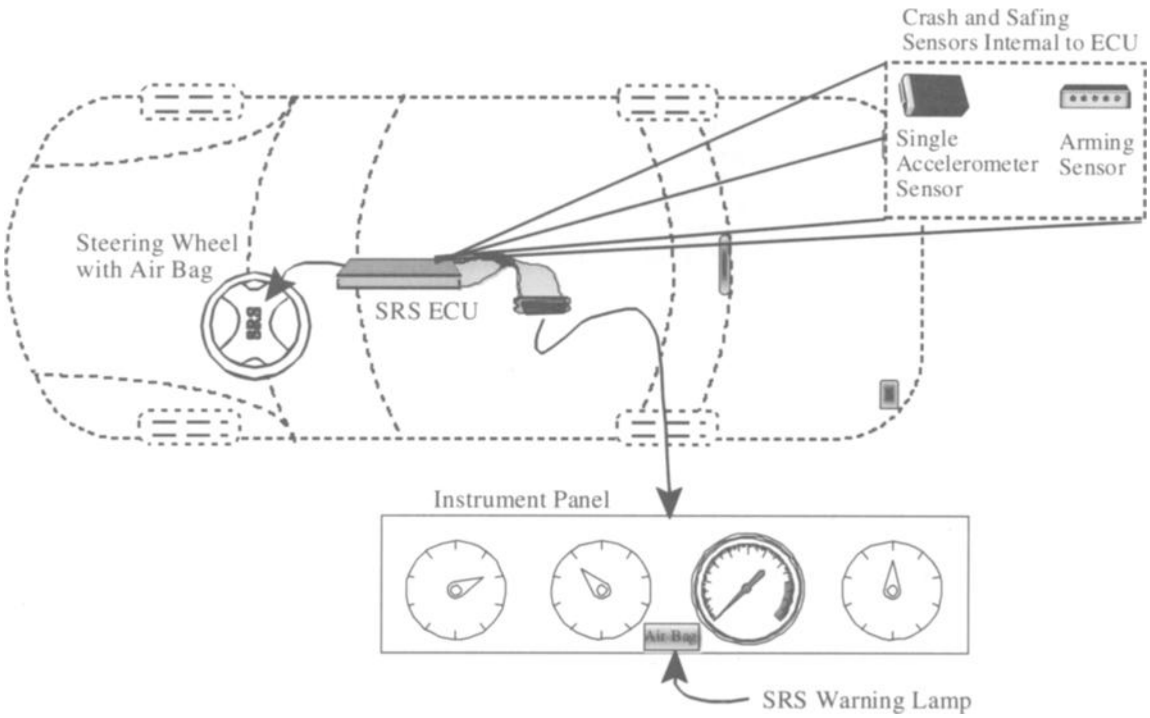


FIG. 3.7—SRS (air bag) system integrated sensor architecture.

to an input force coupled to the housing through the vehicle frame. The displacement of the mass causes it to close an electrical switch, which indicates to the system that an acceleration pulse is detected. Three popular electromechanical designs are rolamite (spring-tensioned rolling cylinder), ball in tube (gas-damped rolling ball), and gas-damped mass.

As an example of one type of electromechanical sensor, Fig. 3.9 shows the line drawing detail of a rolamite sensor. This type of sensor utilizes a cylindrical sensing mass, held in place by an extended flat spring attached to the cylinder and to the frontstop. We can identify the flat spring as electrical contact A and the two fingers as electrical contact B. When the sensor housing is accelerated by an input force directed from the frontstop toward the backstop, the sensing mass tends to remain in place while the sensor housing translates in the direction of the applied force, i.e., moves toward the backstop. A high enough force over time (F/t) produces a greater translation of the housing than of the sensing mass, and this appears as a displacement of the cylinder mass away from the backstop toward the frontstop. As the cylinder displacement increases, it ultimately causes contact A to touch contact B. This closes the internal switch for that sensor location and completes its respective portion of the series circuit.

If we position such a sensor in a vehicle and attach its housing to the chassis, we can detect an acceleration of the chassis at that point. Figure 3.10 shows such a sensor as positioned within a vehicle overlayed with SAE J211/J670e axes where a frontal crash force input in the −X axis direction will cause the sensing mass versus housing displacement described above. Figure 3.11 shows the macro photo detail of an actual sensor cutaway positioned within a vehicle overlayed with SAE J211/J670e axes. Both figures show the flat band-spring controlled cylindrical mass and the contact fingers on the cylinder mass travel path between the backstop and the frontstop.

Many arming sensors still use an electromechanical construction, with a design axis response in the −X axis direction, but almost all contemporary discriminating sensor applications employ solid state or hybrid accelerometers.

3.3.6.2 Solid-State Discriminating Sensors (Integrated-Circuit Accelerometers)

Contemporary crash discriminating sensor technology incorporates thick-film assemblies and etched-silicon devices. In each of these device types, an input force still causes the acceleration and movement of the base structure with respect to an inertial mass, but the mass is an integral lever or pendulum and movement consists of the elastic micro-deformation of that mass, or the micro-bending (flexure) of a cantilever. This micro-deformation (flexure) is detected by sensing variations in resistive strain detectors on the deforming surface of the cantilever, or by sensing a capacitance variation between the mass and an adjacent surface as the pendulum displaces (i.e., the distance between them closes or opens). These changes in electrical characteristics are detected by a translating (conditioning) circuit, which produces a change in voltage output proportional to the mass flexure, and, hence, proportional to the input force that caused either of the flexure types.

The voltage output of the accelerometer is monitored by a translating unit within the ECU microprocessor called an analog to digital converter (ADC). The ADC translates the analog accelerometer voltage into a digital value (directly proportional to the acceleration value) that can be used in MPU calculations. When successive A/D values are saved versus

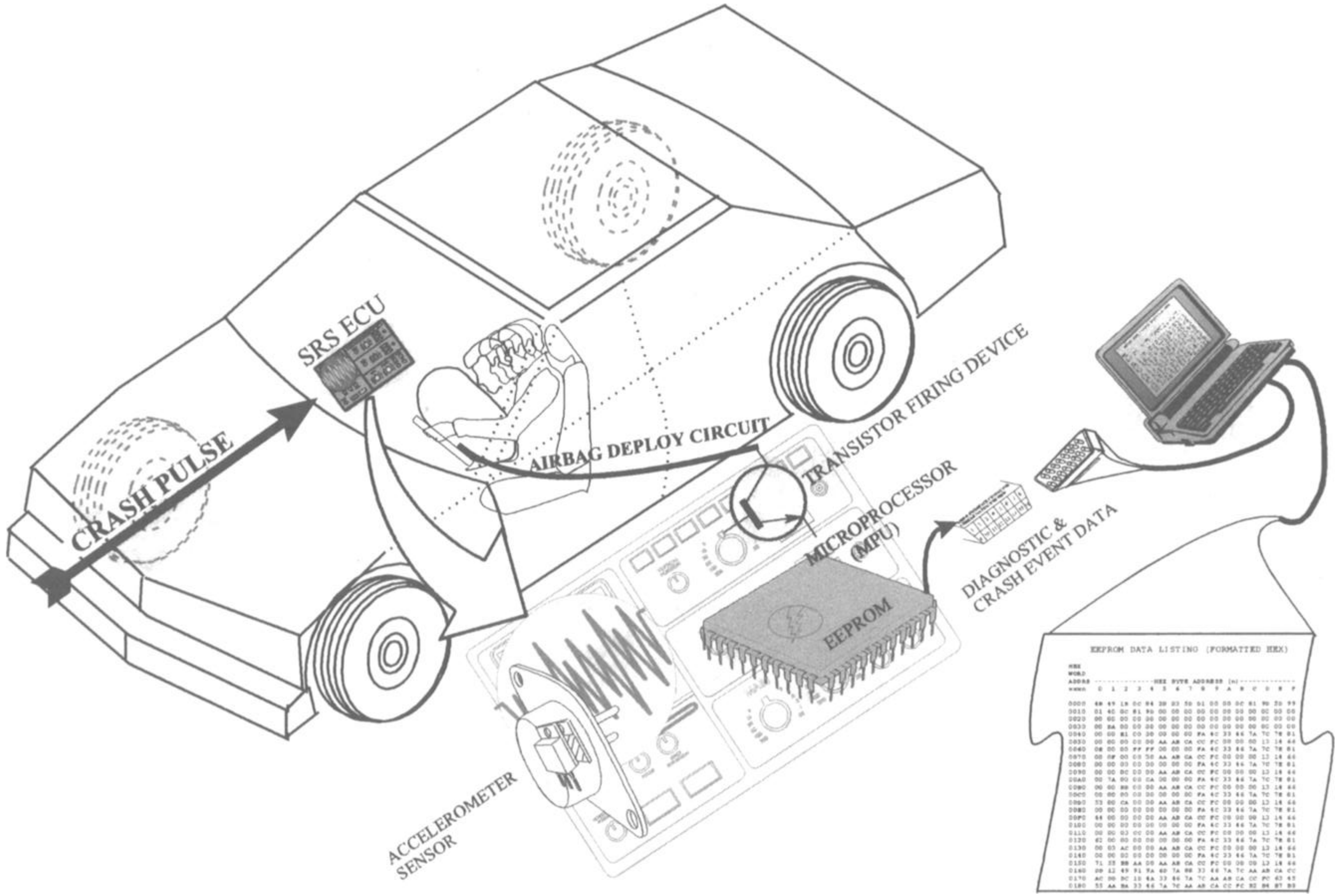


FIG. 3.8—Second generation SRS ECU architecture using an internal solid state accelerometer to detect a crash and internal transistor switches to fire the air bag squibs.

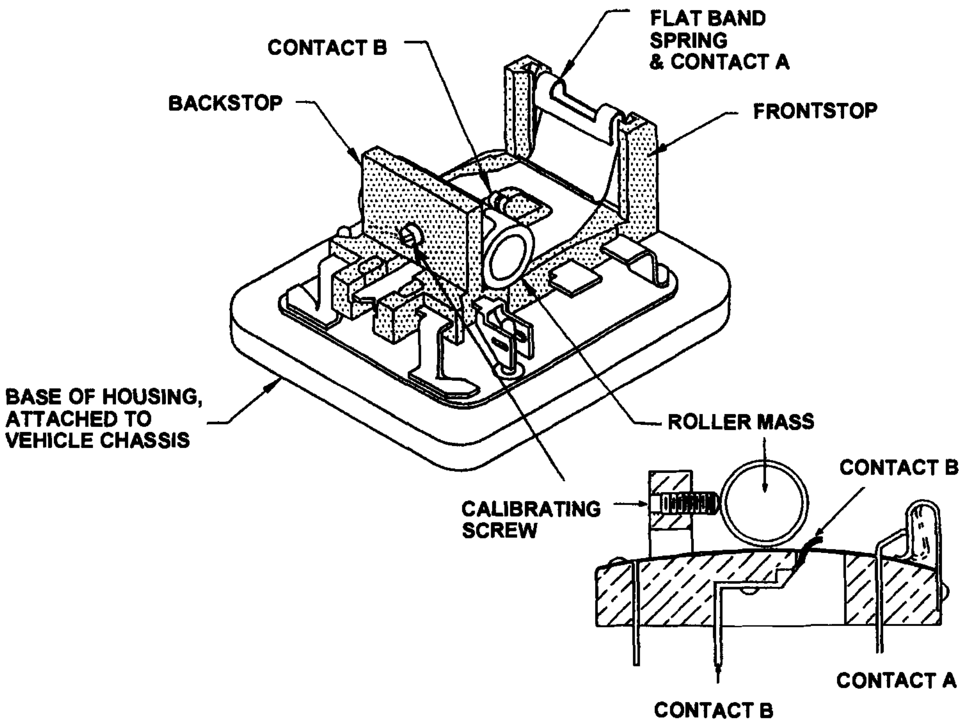


FIG. 3.9—Line drawing of the functional parts of a Rolamite sensor.

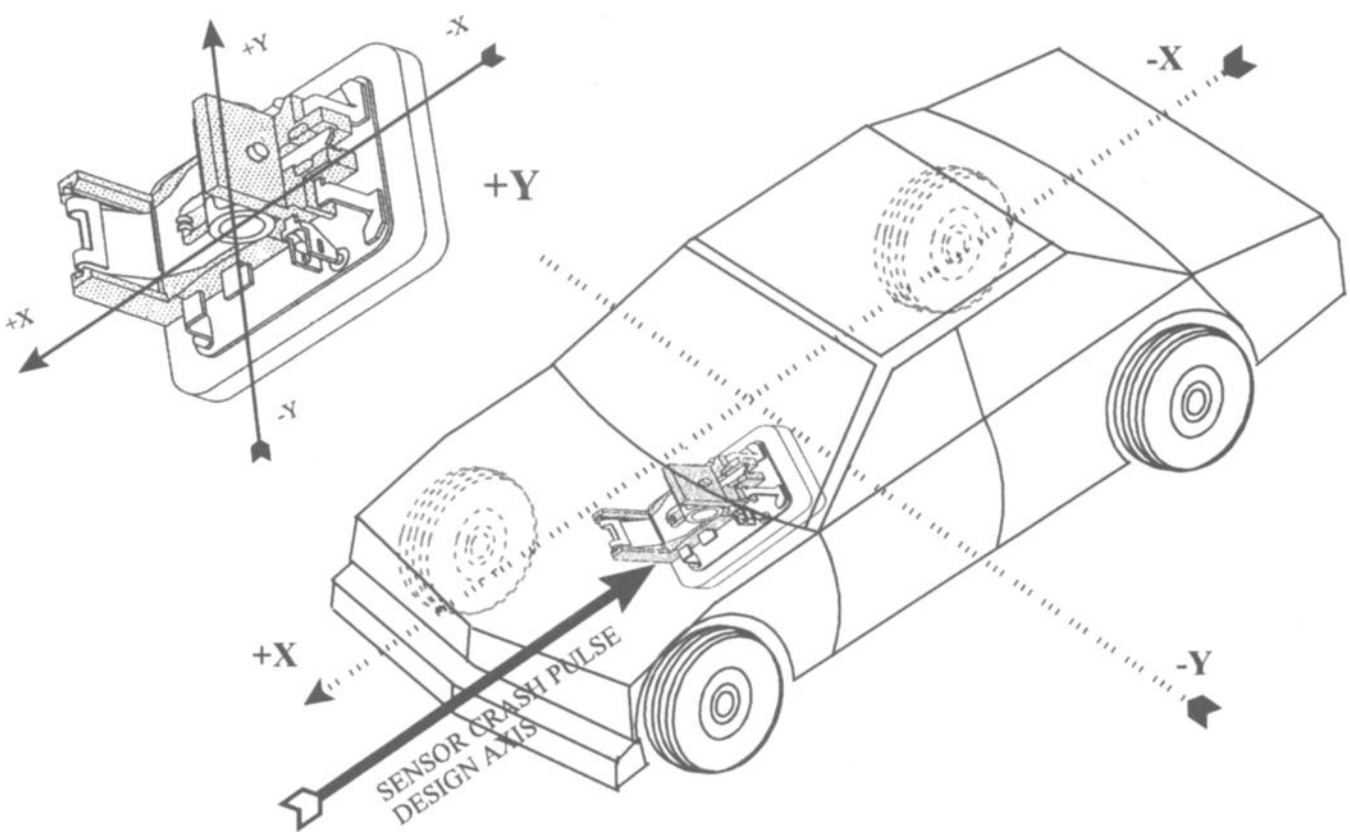


FIG. 3.10—Rolamite electromechanical sensor switch line drawing showing orientation as placed in a vehicle with SAE J211/J670e axes superimposed.

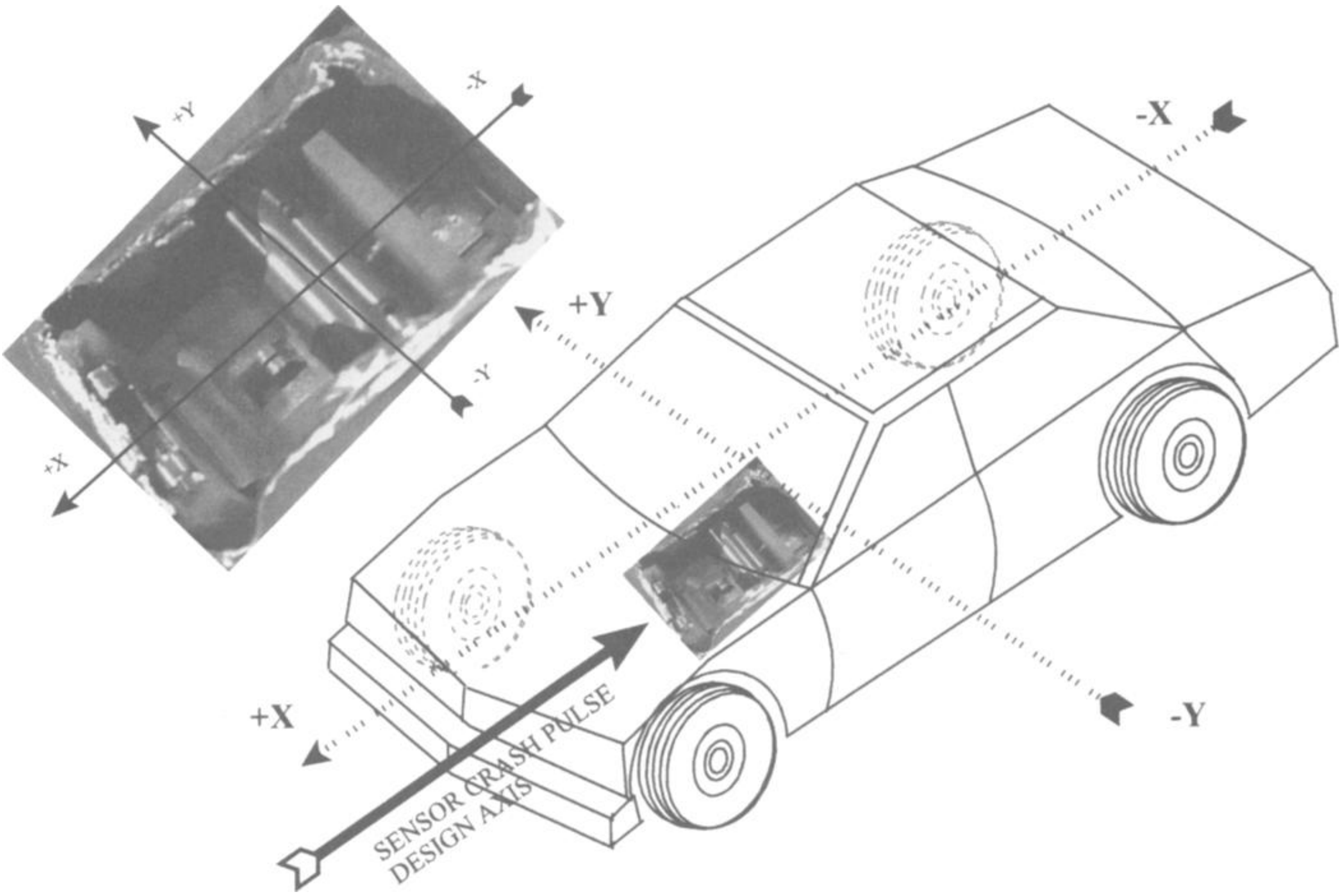


FIG. 3.11—Rolamite electromechanical sensor cutaway photo showing orientation as placed in a vehicle with SAE J211/J670e axes superimposed.

time, we have, in the MPU memory, a table of crash acceleration values versus time, or an acceleration waveform. When such an acceleration table or waveform[11] is detected and recorded, it can be numerically compared to stored injury-threshold tables or waveforms (derived from crash tests) in order to make a firing decision in the subject vehicle.

Examples of two micromachined accelerometer designs are seen in Fig. 3.12. This figure shows a responsive mass, or single-cantilever and piezoresistor deflection retector (A) and a double-cantilever mounting design (B). A photomicrograph of an actual device cross section is seen in (C). This device is constructed from a multilayer silicon sandwich, on fabrication lines similar to those making microprocessor and logic devices. Accelerometers of this type are used in integrated-sensor SRS ECUs.

A second example, Fig. 3.13, shows a thick film multi-axis accelerometer. This device is constructed from an assembly of components deposited on thin ceramic substrates. The substrates are then attached to each other. In such an assembly, the cantilever arm flexure is proportional to the acceleration, and that flexure is detected by a resistive strain detector attached to the flexure surface. In this example, there are actually two orthogonal accelerometers in the same package.

The thick film multi-axis accelerometer in Fig. 3.13 was used in the top ECU of Fig. 3.14 (earlier design). Both of those ECUs utilize two orthogonal accelerometers to detect a crash pulse. The packaging of these accelerometers is achieved with the two different designs shown in Fig. 3.14. One ECU uses a combined assembly in one package, and the other uses two separately packaged units.

When two separate orthogonal accelerometers are used, it is possible in some cases to estimate the actual PDOF by geometrically resolving the acceleration vectors impressed upon each accelerometer.

3.3.7 Air Bag Modules

Air bag systems can have driver, passenger, side, and head inflatable restraint modules. The great majority of air bag modules consist of a propellant canister and a folded fabric envelope, both behind a covering (fascia) with a tear-seam. When actuated through electrical ignition, the ignited propellant generates a high volume of gaseous output, which is directed into the folded fabric envelope, causing it to quickly inflate into the folded air bag envelope, forcing it to burst through the cover tear-seam, and then inflating into an air

[11]Or its velocity product, $\Delta V_n = \langle a_n \rangle \, t_{\text{sample}}$ and $\Delta V_{\text{event}} \; \Sigma \; \Delta V_1 + \Delta V_2 + \Delta V_3 + \cdots + \Delta V_n$.

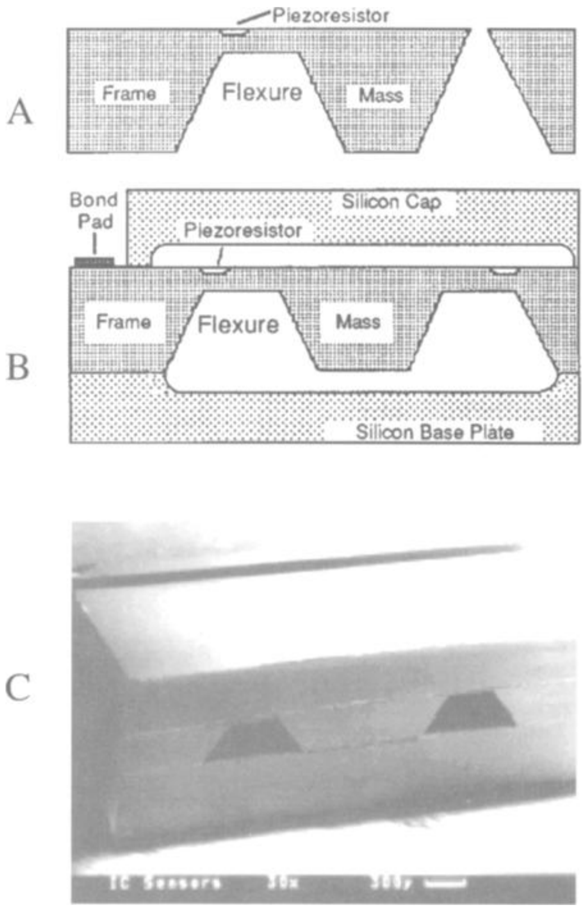


FIG. 3.12—Solid state micromachined accelerometer designs showing (A) responsive mass, single-cantilever and piezoresistor deflection detector, (B) cross section of double-cantilever mounting design, (C) photomicrograph of actual device cross section. Figures used Courtesy of Measurement Specialties, Inc., IC Sensors Division, Milpitas, CA.

cushion that serves to restrain the occupant during a crash deceleration ride down.

The propellant canister, commonly called a *squib*,[7] consists of two sections—a small igniter capsule in the center of a larger propellant cavity. The igniter capsule contains a wire surrounded by a small initial combustible charge. When sufficient current is passed through the wire, it heats (and usually separates, like a fuse), and the initial charge ignites and burns. This, in turn, ignites the propellant, typically sodium azide, which surrounds the igniter. The propellant is positioned within the canister so as to create a uniform burn of the propellant charge. The gasses given off upon propellant ignition are routed through diffuser screens to cool and filter them before they enter the folded envelope that inflates to become the air bag.

The process is exothermic, i.e., heat producing, and hot output gases are created in the process. The canister is designed so that the hot gasses pass through particulate and cooling filters before reaching the folded fabric envelope. A line drawing of a typical canister assembly is shown in Fig. 3.15.

3.4 OPERATION AND TIMING

3.4.1 Crash Timing

Accepted design considerations call for the air bag to be fully inflated and in position to provide a fully deployed cushion for occupant protection as he or she moves forward within the car as it decelerates during a frontal crash. Appropriate deployment timing varies with the nature of the crash, but one industry guideline, developed for barrier-like crashes, is that the air bag must fully inflate before the driver occupant has moved forward 5 in. with respect to the fixed coordinates of the vehicle. This guideline is known as the "5-30 rule."[12]

Figure 3.16 shows coordinated illustrations of vehicle impact status, air bag deployment throw, and occupant position versus time after a fixed barrier impact for a case where the air bag is fully inflated before the moving driver contacts its leading edge. This illustrates a desired air bag deployment sequence, meeting the 5-30 rule.

3.5 DIAGNOSTICS, DTCS, AND CRASH DATA

3.5.1 Retrieving DTCs and Crash Data

All air bag ECUs (diagnostic and/or control modules) use EEPROM or flash memory to save DTCs and many save crash event data. Most post-1996 SRS ECU EEPROM or flash memory data are usually accessed via the OBD-II network port using a scanner or a microprocessor interface. Many scanners are designed to interface with a dealer diagnostic workstation,[13] and some scanners incorporate the ability to print the downloaded data directly. Examples of scanners used for downloading of emissions-related DTC and emissions-DTC freeze frame data from various ECUs have already been shown in Chapter 1, and air bag DTCs are usually read with these same scanners.

However, the capability for accessing crash-event parameter snapshots, including the engineering-level data, is not usually programmed into dealer-level scanners or aftermarket scanners.[14] Accessing engineering-level crash-event parameter freeze frames typically requires special access codes and/or special interface connections. This is conceptually shown in Fig. 3.17, for a direct ECU download interface to

[12]The 5-30 rule was established on the basis of a 30 mph frontal barrier collision, wherein an unrestrained driver will have moved 5 in. forward from his or her seated position at the instant of the crash approximately 50 ms to 70 ms into the crash. Since the air bag deployment time is approximately 30 ms (max) from the electrical signal to full "air cushion" (fully inflated envelope), the system is required to provide the electrical deploy signal at least 30 ms before the occupant will have moved 5 in. (as little as 50 ms into the crash), in order to have the air cushion fully inflated before any driver contact with the air bag envelope. Thus, the sensor output signal must be provided to the air bag squib no more than 20 ms into the crash.

[13]Dealer diagnostic work stations usually consist of a stand-alone personal computer, monitor, printer and modem. This allows the work station to communicate with an associated scanner, display, and print data from the scanner; download data from a central network to the scanner (for vehicle ECU reprogramming, etc.); and upload data from a vehicle to the central network for remote analysis.

[14]And certainly cannot be determined from blink-code diagnostics.

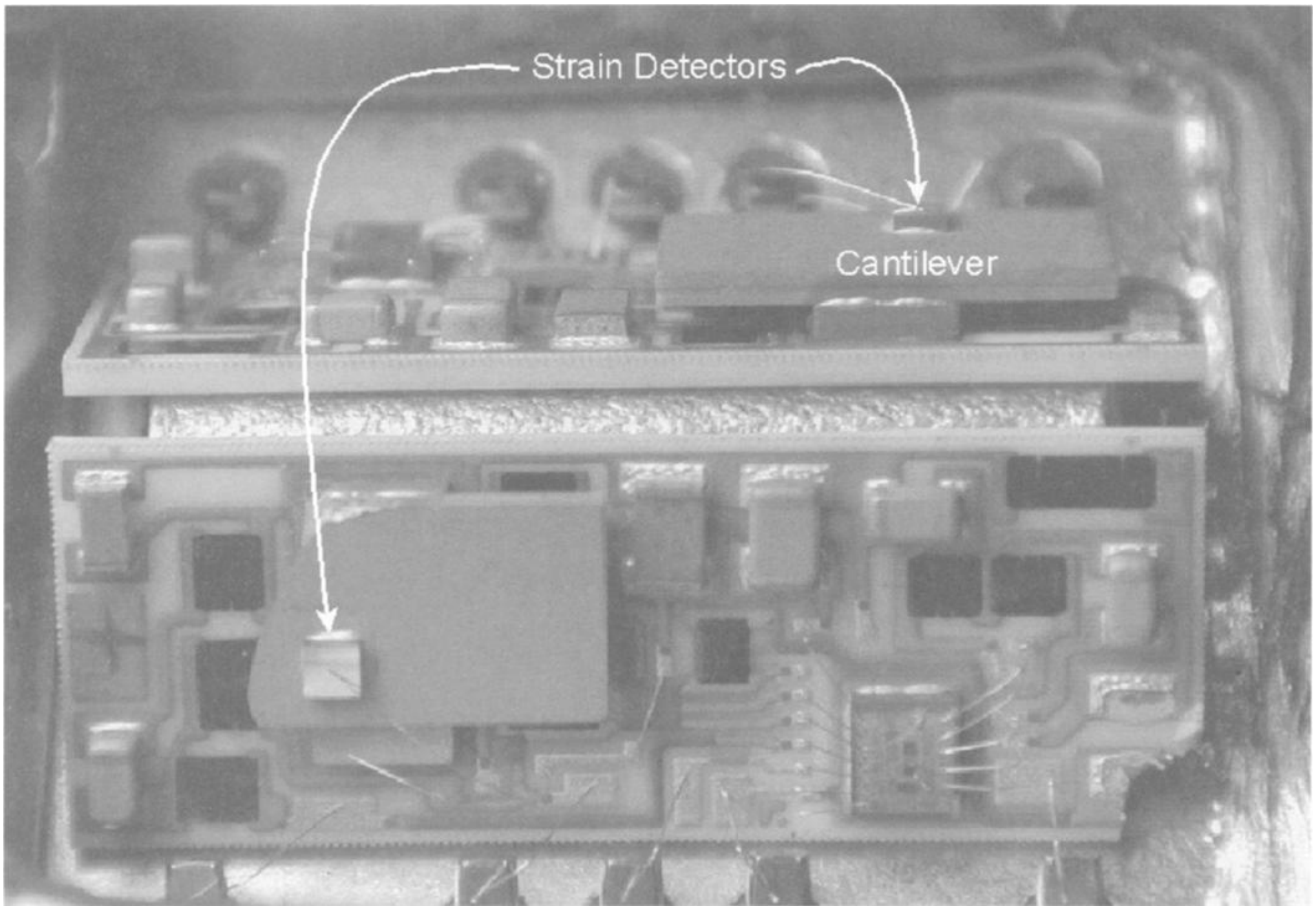


FIG. 3.13—Example of twin orthogonal thick film accelerometers. Note lever arm and strain-sensing element to detect cantilever distortion (strain) (from Fig 3.14 unit).

a scanner that prints an EEPROM data list in hexadecimal format.

Examples of American, Asian, and European versions of scanners used to accomplish the EEPROM download process are shown in Figs. 3.18, 3.19, and 3.20, respectively. Each of these scanners has individual data output formats and the available crash parameters vary.

In the event that the vehicle network is damaged in a collision, it is desirable to be able to communicate with the SRS ECU out of the vehicle environment (i.e., perform a bench top interrogation). Many scanners can be configured to do this. Two examples of bench top SRS ECU test interfaces are shown in Figs. 3.20 and 3.21. Another method to interrogate an SRS ECU from a severely damaged vehicle is to remove it, install it in a surrogate vehicle, and then interrogate it. This requires that the surrogate vehicle be interrogated (baselined) first to demonstrate that it will neither add nor subtract from the data in the subject SRS ECU.

A new type of scanner, the crash data retrieval system (CDR), was introduced on the market in 2000 by Vetronix. The CDR was developed in cooperation with General Motors (Chidester 1999) and has the ability to read, print, and save enhanced SRS ECU data using the CDR interface and a laptop computer. Enhanced data includes parameters originating in other ECUs and communicated via the vehicle serial data network to the SRS ECU (GM SDM) and stored in the SDM EEPROM. Such other ECU data include five seconds of pre-crash data, including brake switch status, vehicle speed, percent throttle, and engine RPM.

An example of a collision-damaged vehicle where both air bags deployed is shown in Fig. 3.22, and the CDR interface to that vehicle is shown in Fig. 3.23. The chart of pre-impact conditions for that vehicle is shown in Fig. 3.24, with the last conditions saved before the crash noted on the −1 second line. However, in actuality, the −1 second line conditions can have occurred from 20 to 980 ms before the crash event is initiated (algorithm enable), so one has to be careful when using that data (Kerr 2000). Actual crash Delta V data output capability is planned for later versions of the CDR, but was not active for certain SDM types as of this writing.[15]

[15]The CDR is the first publicly available scanner to provide a translation of the air bag ECU EEPROM hexadecimal data. However, not all hexadecimal data is translated. For instance, the CDR does not identify which air bag DTCs were in history at the time of the crash event, or which DTCs are currently active. Additionally, the CDR does not indicate which deployment criteria were used, or the existence of multiple crash events. However, this information is contained in the hexadecimal data.

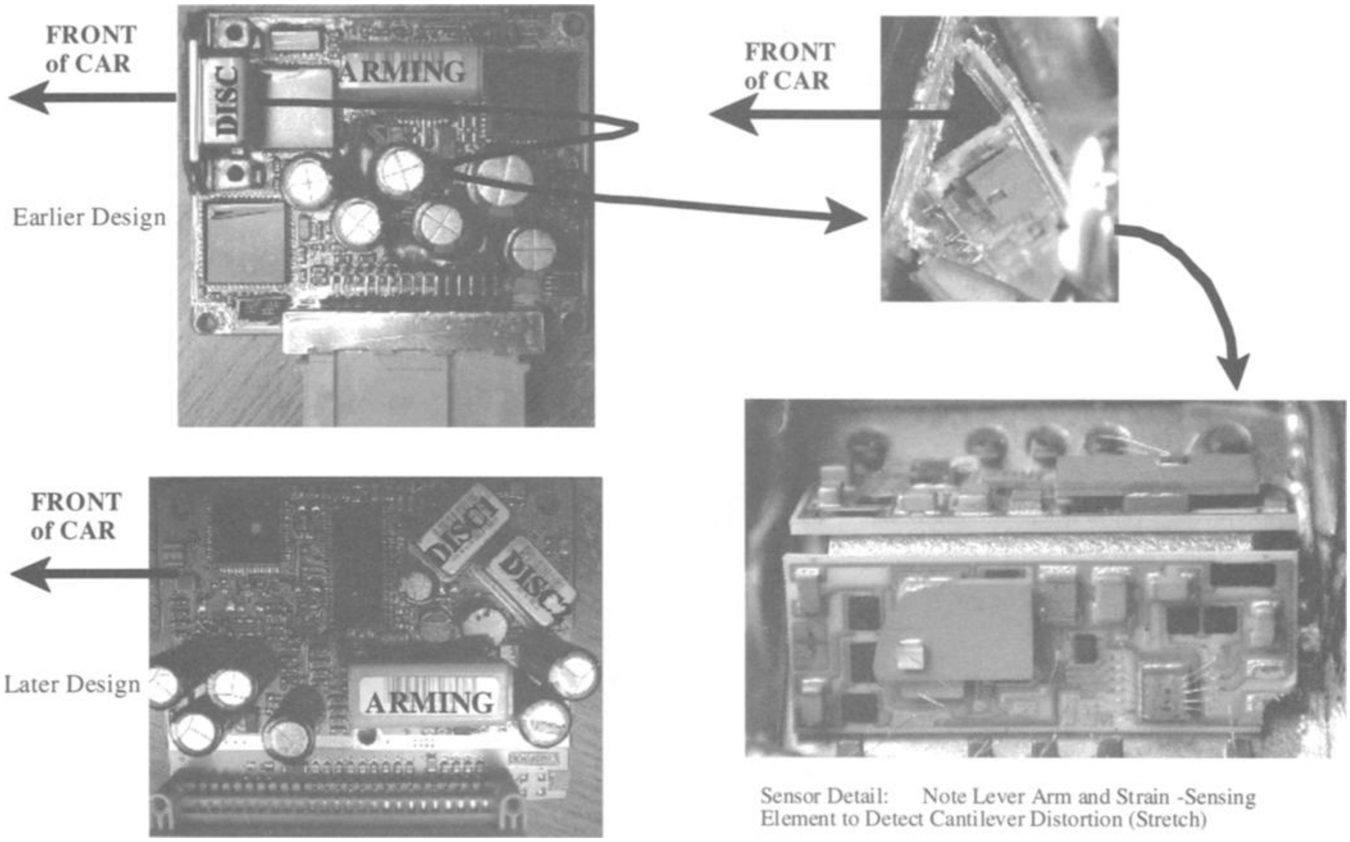


FIG. 3.14—Alternate design for two integrated sensor SRS ECUs from the same 1994 vehicle platform. Note that earlier design had composite orthogonal-axis discriminating sensor in same package while later design used two separate orthogonal-axis accelerometers. See Fig. 3.13 for accelerometer detail.

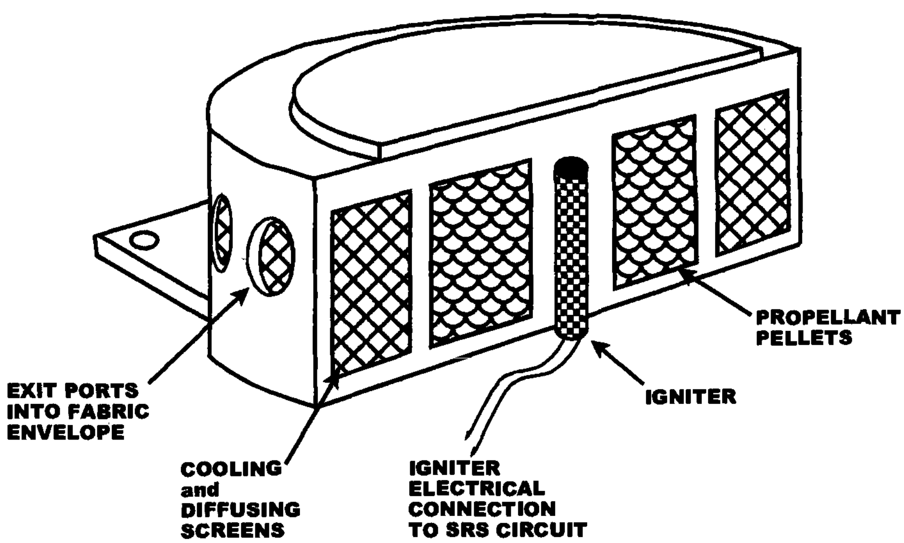


FIG. 3.15—Example driver air bag squib showing canister, filtering and cooling screens, propellant, and igniter.

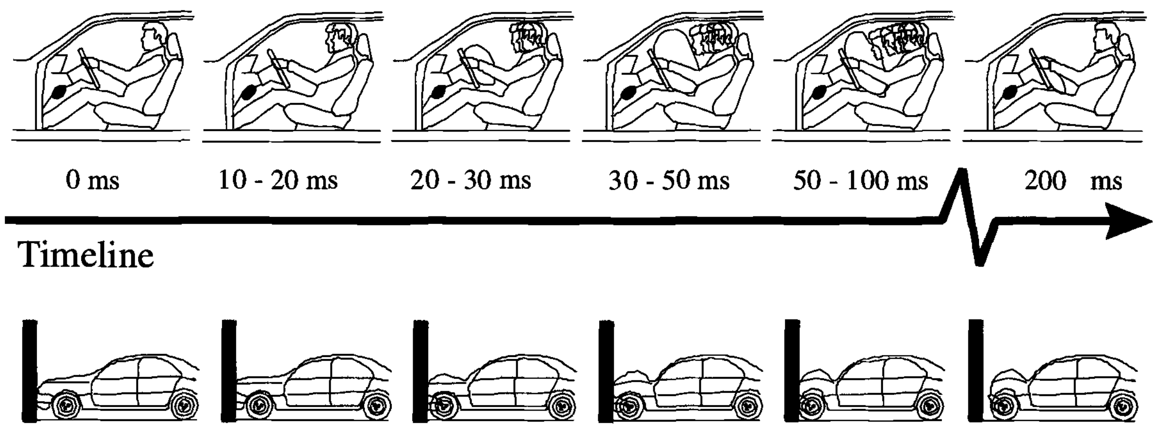


FIG. 3.16—Desired air bag deployment timeline in a frontal barrier crash.

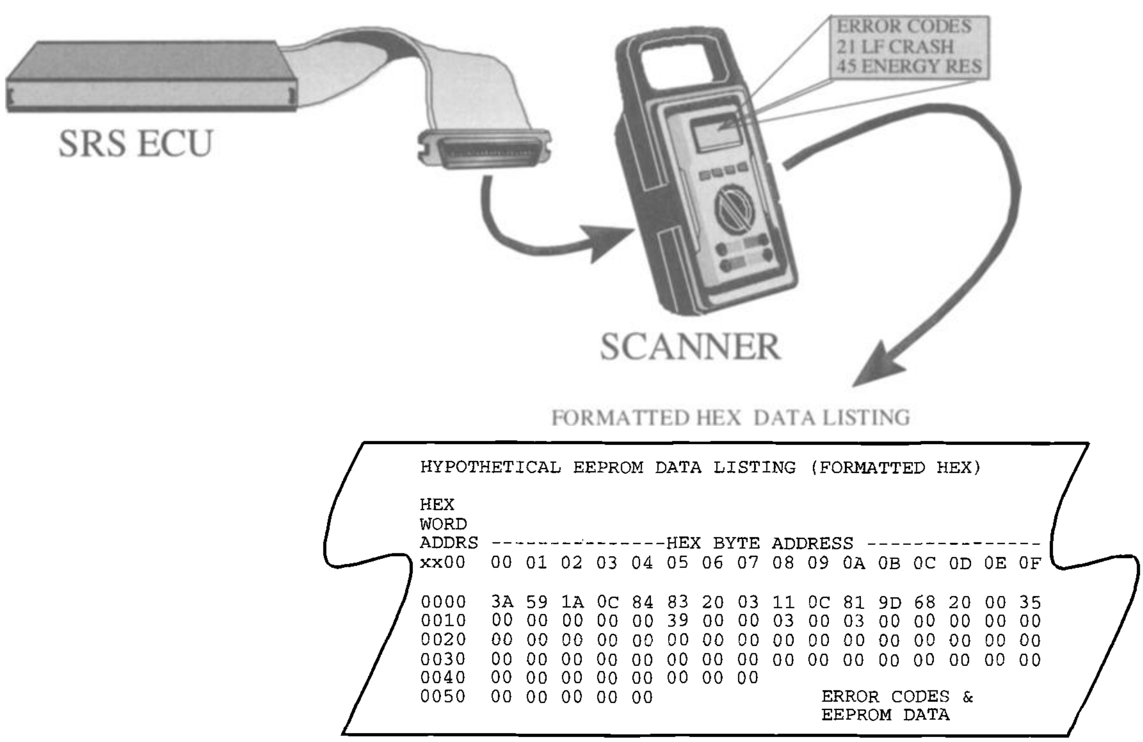


FIG. 3.17—Schematic of SRS (air bag) ECU diagnostic interrogation using a scanner.

Additionally, because the CDR employs a laptop computer for its vehicle ECU EEPROM/flash-memory downloads, the data can be almost immediately uploaded via cell phone wireless internet data link to a laboratory for further analysis. This is shown in Fig. 3.25 and was done for the data download in Figs. 3.22 through 3.24. In that case, the CDR data record was received and printed at ASA Labs before I returned from the field download, 30 miles away. An additional analysis based on the CDR data documented in Figs. 3.22 to 3.24 is presented in Chapter 6, Case 6.

A last, and sometimes key, feature of the CDR is that it can also download EEPROM data from a SDM recovered out of the vehicle, in the event the vehicle is too damaged to use the OBD-II serial port. This is shown in Fig. 3.26 and is similar to the laboratory downloads shown in Figs. 3.20 and 3.21.

In the above CDR example, the SDM (air bag computer) records brake status, throttle %, engine RPM, and vehicle speed by monitoring these parameters on the vehicle network data line. None of these parameters are used by the

FIG. 3.18—Tech 1 scanner reading an SRS ECU and printing a paper tape with data and addresses in hex formatted list on paper tape.

SDM to determine air bag deployment. Hence, the enhanced SDM (saving data from other-system ECUs) can be said to be the first passenger vehicle device to function as an event data recorder[16] (EDR) in a manner similar to an aircraft digital flight data recorder. The comparative capabilities of ground vehicle versus aircraft EDRs is discussed in the Preface and in Appendix E, and the future of passenger vehicle EDR capabilities are again discussed in Chapter 7.

3.5.2 Deriving DTCs and Crash Data Formats from Raw Hex Data

For various versions of SRS systems as applied to different model vehicles, there are various versions of the content, format, and scaling of its crash-event and freeze frame data. Since each version of such data has a specific format and mathematical interpretation scheme, a hexadecimal list with no translation of its contents is not very useful.

There can be between 128 and 1024 bytes of data in the EEPROM that are read out in hexadecimal format. These are always identified by address location (also in hexadecimal). Each byte of data has eight data bits, and can be interpreted in one of several modes (decimal equivalent, character equivalent, mask mode by bit, and mixed mode). Additionally, the arithmetic conversion number base for certain parameter counts is not fixed at the standard hexadecimal reference base (256).

Given such variable interpretations, the content and interpretation format(s) of various data fields of EEPROM data are often summarized in a worksheet.[17] Such worksheets are usually derived from multiple engineering specifications, software listings, and electrical schematics. These documents actually define how the ECU operates and the content, format, and scale factors with which the ECU records data in EEPROM or flash memory.[18]

To illustrate such a data scheme and its interpretation process, a fragment of hypothetical crash event data shown below, with its interpretation:

[16]A device is said to be an EDR when it accumulates and saves data parameters from other systems and ECUs for purposes of readout after a crash event.

[17]Mostly, but not completely. Not all data fields are found in all worksheets.

[18]These engineering specifications, software listings, and electrical schematics are universally considered to be manufacturer-proprietary and are usually available only under confidential non-disclosure agreements.

Excerpt of Hypothetical Crash Event Data

DATA BYTE ADDR	DATA - BYTE VALUE - HX	DEC	BINARY	TRANSLATED MEANING & ENCODING	EVALUATION, HYPOTHETICAL EXAMPLE
0000:	4B	75	01001011	SOFTW IDENT version, level	Version 4, Level B
0001:	49	73	01001001	SOFTW DATE HI yr, month	(199)4, Sept
0002:	1B	27	00011011	SOFTW DATE LO day	27th day
0003:	0D	13	00001101	TOTAL IGN CYCLE COUNTR, HI BYTE, 256 per count	3328
0004:	95	149	10010101	TOTAL IGN CYCLE COUNTR, LO BYTE, units count, 0-255	+149 ==> 3477, total ign cycles
0005:	83	131	10000011	SRS Lmp, ON/OFF cont, cyc prior to cur igct 125mx	b7=on/off, SRS lamp = ON for 3 cycles
0006:	20	32	00100000	HISTORY FAULT FLAGS: 13 14 15 16 18 20 21 25	fault 15 in history
0007:	04	4	00000100	HISTORY FAULT FLAGS: 30 33 35 41 42 43 61 62	fault 43 in history
0008:	11	17	00010001	CRASH DATA Snsr Close Seq, Base Time, 1 ms/ct	bit 7=0=arming first, bits 6-0=17 ms
0009:	0D	13	00001101	CRASH DATA IGN CYCLE COUNTR, HI BYTE 256/count	3328

The comparative data output screens of the laboratory fixture shown in Fig. 3.21 show three data formats: raw hexadecimal, address-formatted hexadecimal, and address/hex/decimal/binary/text-translation.[19] This last format provides an immediate download interpretation, as illustrated in the hypothetical data excerpt above.

3.5.3 Crash Data and Freeze Frame Parameters That Can Be Associated with SRS Deployment Events

Below is a representative list of parameters that can be saved in the crash data and freeze frames associated with an air bag/ETR deployment event. Some parameters will obviously be saved in the SRS ECU, and others may be saved elsewhere, depending on design complexity and the level of systems integration.

1. Crash/Near Crash History Fault Codes
2. Crash/Near Crash Ignition Cycle Fault Codes
3. Crash/Near Crash Active Fault Codes
4. Global History Fault Codes
5. Crash/Near Crash Internal ECU Fault Codes
6. Global Internal ECU Fault Codes
7. Total Ignition Cycle Count
8. Crash/Near Crash Ignition Cycle Count
9. Crash/Near Crash Warning Lamp Status
10. Crash/Near Crash Delta V Data
11. Crash/Near Crash Algorithm Enable Status
12. Crash/Near Crash Jerk Threshold Exceeded Status
13. Crash/Near Crash Energy Boundary Threshold Exceeded Status
14. Crash/Near Crash Velocity Boundary Threshold Exceeded Status
15. Crash/Near Crash Driver Seat Belt Status
16. Crash/Near Crash Passenger Seat Belt Status
17. Time between Near Crash and Crash (each crash)
18. Crash Algorithm Enable to Overlap or Arming Sensor Closure Time
19. Crash Algorithm Enable to Crash Time
20. Crash Algorithm Enable to Discriminating Sensor Closure Time
21. Near Crash Algorithm Enable to Max Delta V
22. Near Crash Max Delta V
23. Vehicle Speed Before Algorithm Enable
24. Engine Speed Before Algorithm Enable
25. Throttle Position Before Algorithm Enable
26. Brake Switch Status Before Algorithm Enable
27. Seat Occupancy Detection/Discrimination
28. Side Air Bag Data
29. Passenger Air Bag On/Off Switch State

Examples of certain specific SRS crash data and/or freeze frame parameters that can be derived from examining EEPROM/flash-memory and analyses based on that data are shown in the case examples in Chapter 6.

[19]The Hex/Decimal/Binary/Text panel in Fig. 3.21, showing the text translation of corresponding decimal/binary data, is purposely obscured to prevent communicating proprietary data and formats.

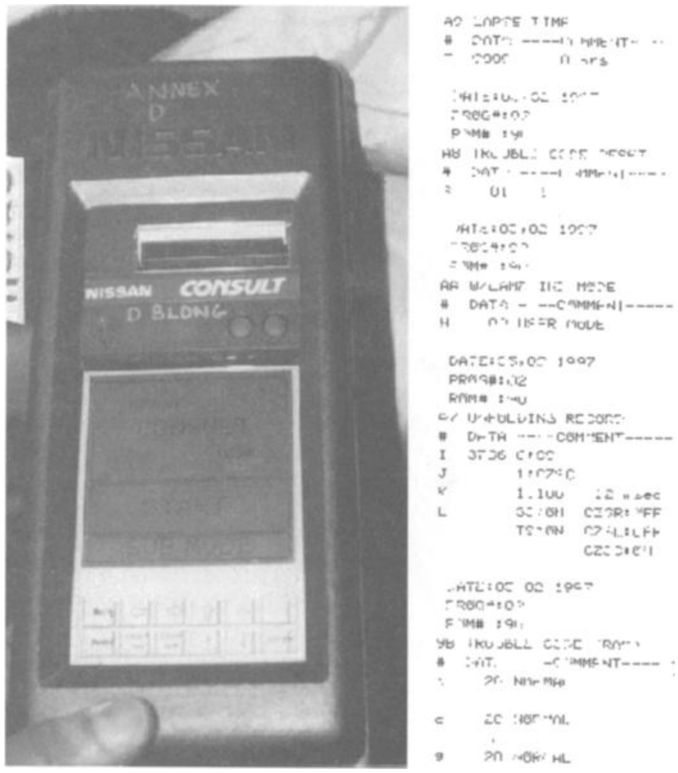


FIG. 3.19—Consult scanner reading an SRS ECU and deployment record segment and resulting paper tape list.

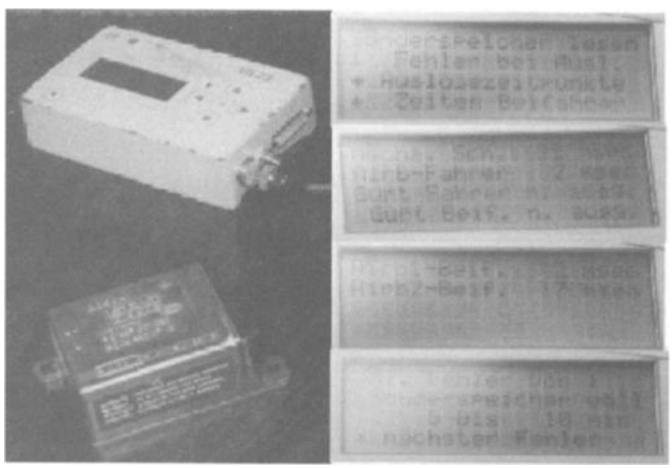


FIG. 3.20—Bosch VS-23 scanner reading an SRS ECU, with deployment data shown in an LCD window.

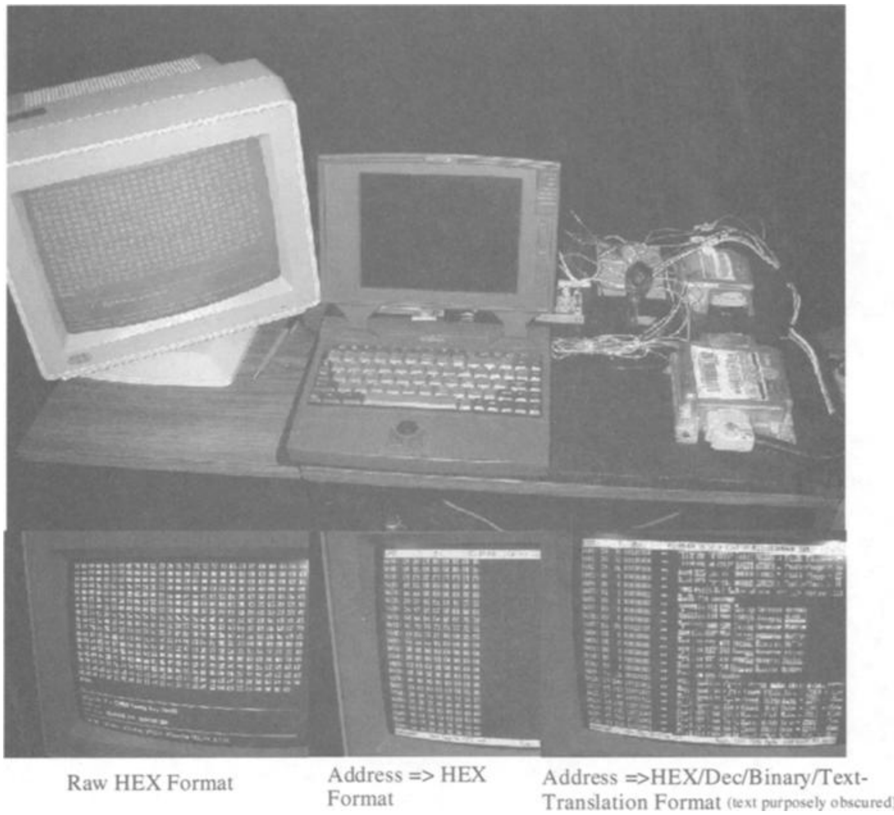


FIG. 3.21—ASA laboratory download of SRS ECU data using a laptop computer and a serial interface. Interpreted data saved as a computer file for later printing.

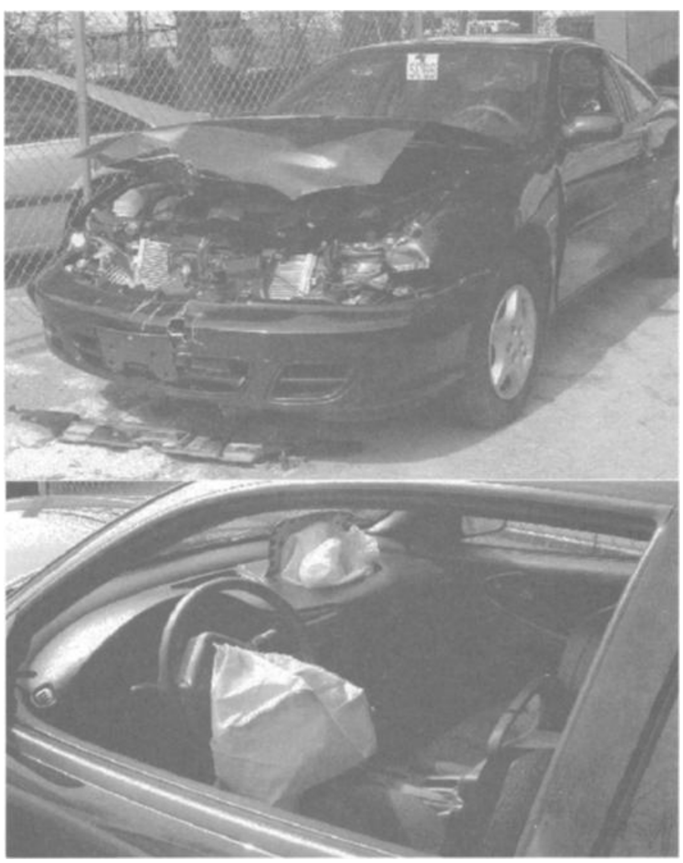


FIG. 3.22—A 1999 domestic vehicle with two deployed air bags.

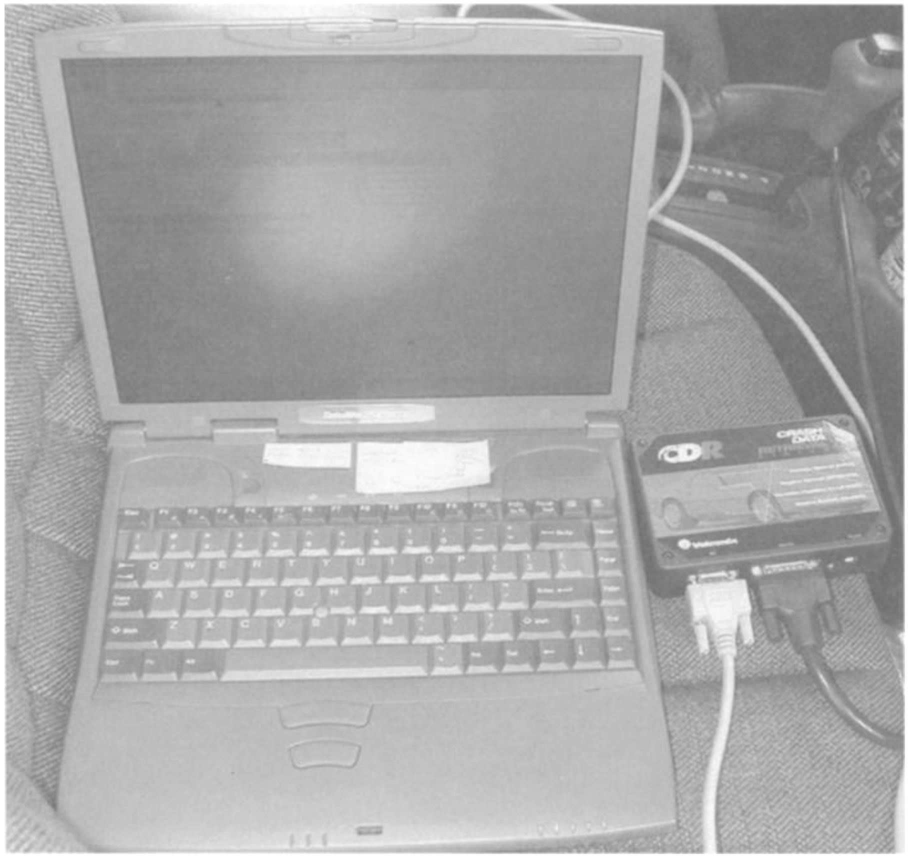


FIG. 3.23—In-vehicle interrogation of the SRS ECU for crash data record in the 1999 domestic vehicle, using laptop computer and Vetronix CDR interface.

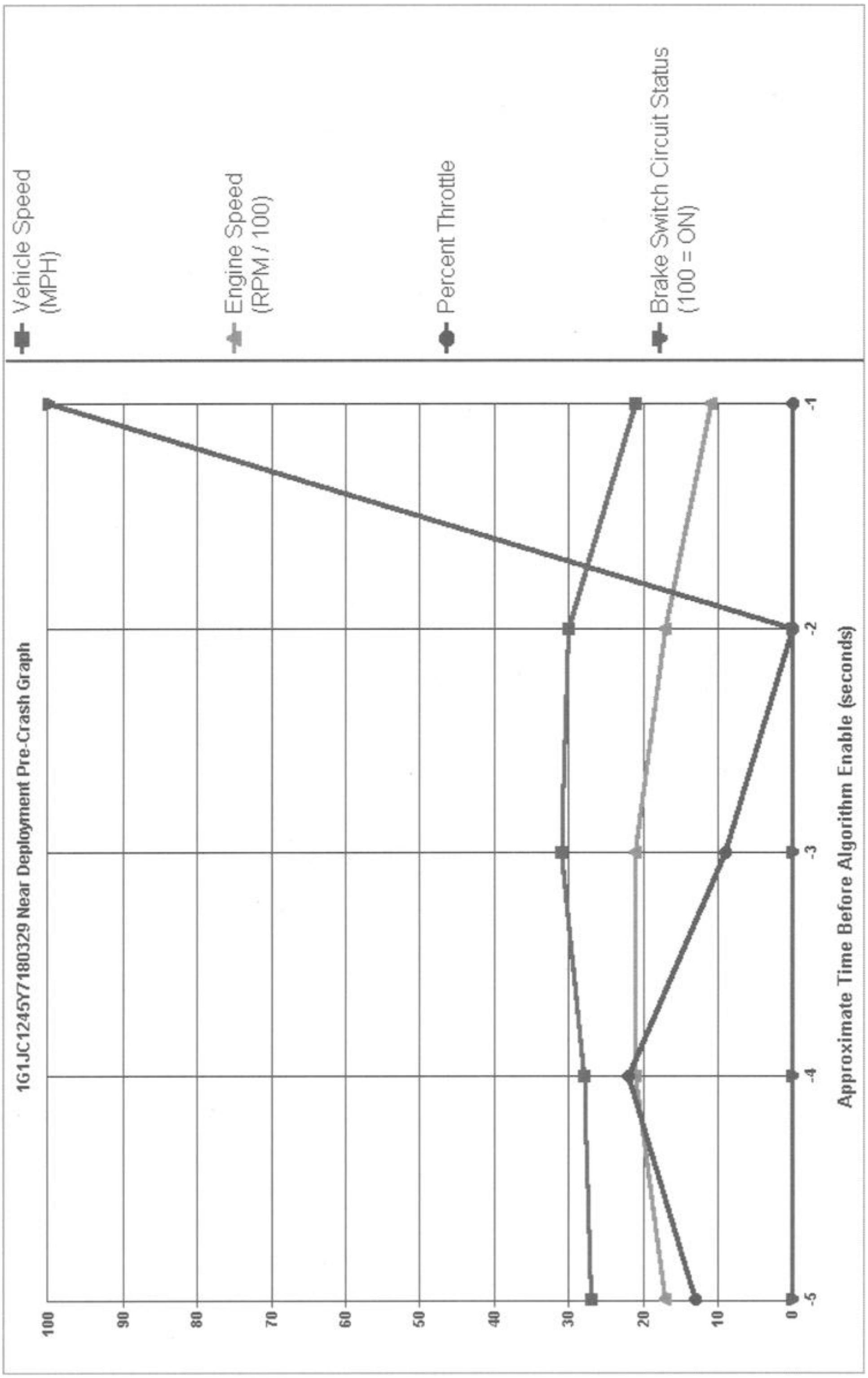


FIG. 3.24—Pre-crash data record downloaded from an SRS ECU in a 1999 domestic vehicle.

FIG. 3.25—A corollary feature of in-vehicle ECU EEPROM/flash memory downloads using laptop computers is that the data can be almost immediately uploaded via cell phone wireless data link to a laboratory for further analysis.

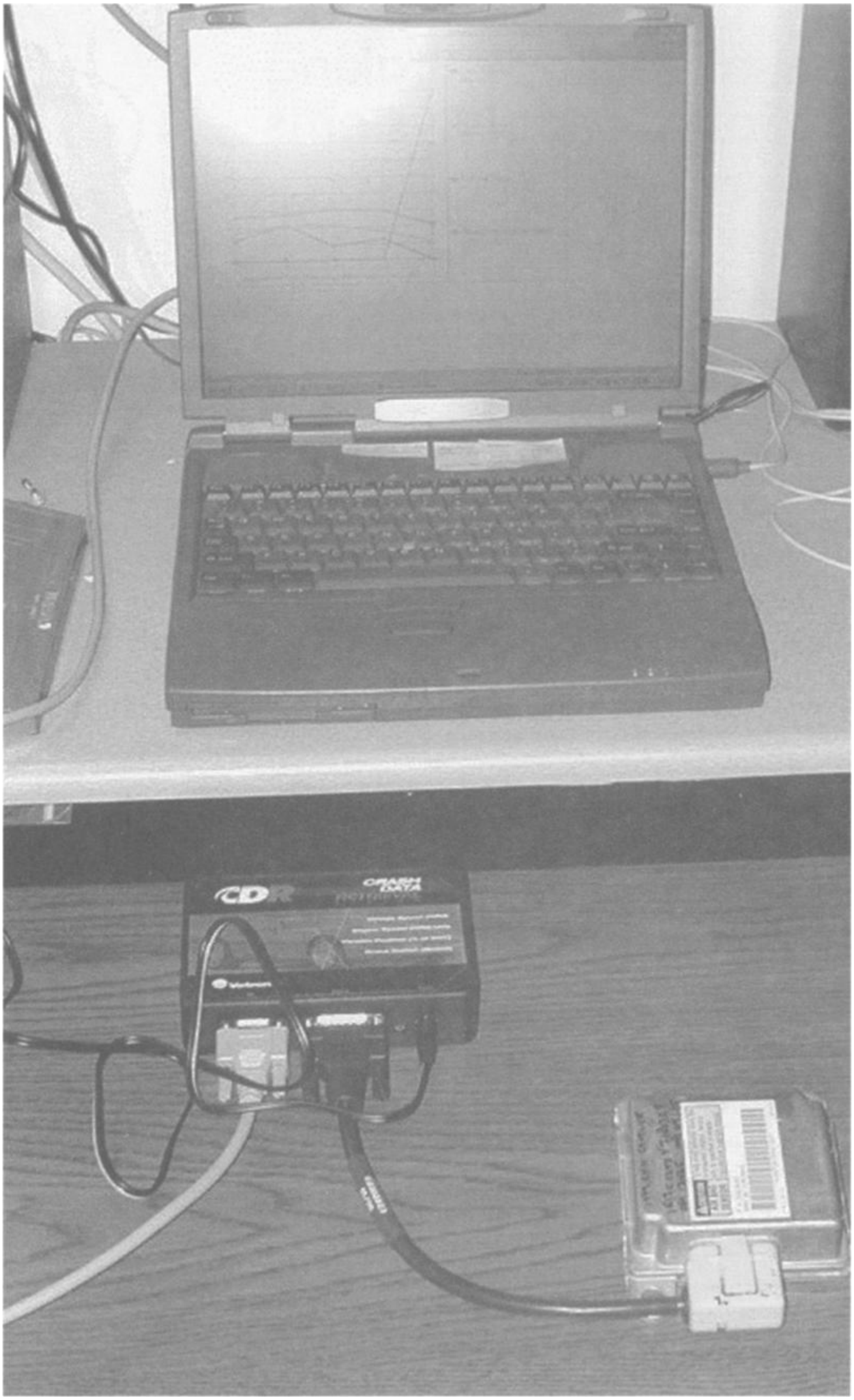


FIG. 3.26—Benchtop interrogation of the 1999 domestic vehicle SRS ECU for crash data record in the, using laptop computer and Vetronix CDR interface. The data downloaded with the SRS ECU in and out of the vehicle was identical.

A Review of Antilock Braking and Traction Control Systems

4

4.1 BRAKING SYSTEM FUNDAMENTALS, FOUNDATION BRAKES

THERE ARE TWO USUAL FORCE INPUTS to a motor vehicle: engine torque to provide acceleration (+X acceleration) and brake friction to provide deceleration (–X acceleration).

When an operator actuates the brake pedal, he or she is actually pushing on a lever that pushes a piston in a master cylinder to generate hydraulic pressure that is transmitted through the brake lines to the wheel actuators (either wheel cylinders or caliper pistons). The wheel actuators force a friction material (brake shoes or disk pads) against a rotating surface (brake drums or disk rotors) to generate a force that stops the vehicle. The energy to stop the vehicle is normally dissipated as heat in the drums or rotors. Thus, applying the brakes is really the act of dissipating the rolling energy of the vehicle as heat, hence slowing the vehicle down. A simplified schematic of a foundation brake system is shown in Fig. 4.1.

The operation of the braking system depends on the integrity of the hydraulic system. Modern boosted master cylinders can generate 2000 psi or more, and the hydraulic system must distribute that pressure without leaking. Almost all modern braking systems use a booster (or operator force amplifier) that uses engine vacuum to increase the force the brake lever applies to the master cylinder. Generally, disk brakes require higher application pressure than do drums because they are not self-actuating. When drum brakes are combined with disk brakes in a vehicle (usually with drums in the rear), there is always "a proportioning valve" to proportionally reduce the effective hydraulic pressure at the drum brake wheel cylinders and to always keep the rear wheels turning to preserve directional stability.

4.2 ANTILOCK BRAKING SYSTEMS

A vehicle braking system, including the tires, is most effective, i.e., produces the optimum retarding force, when the wheel speeds are approximately 85 to 90% of the vehicle speed. The difference (100% − 85% = 15%) is called the percent slip of a particular wheel. The 10 to 15% slip retarding force is greater than the locked wheel retarding force, so optimum braking is achieved when the slip is 10 to 15% and no more. Over-applying foundation brakes can cause wheels to lock (100% slip), so a system that prevents this can improve braking effectiveness. Antilock braking systems (ABS) have been developed to do this.

However, prevention of lock to improve braking effectiveness is not the most important reason for ABS. Once a wheel is locked, it does not provide any lateral control of the vehicle (+/–Y axis), and, if multiple wheels lock, the vehicle will start to yaw. This means that if the rear wheels lock, the vehicle will tend to spin out (rear end moving forward), and if the front wheels lock, the vehicle cannot be steered. Control of vehicle track is the most important reason for the use of ABS.

It has been shown that for poor road conditions (sand, ice, snow, water, etc.), a system that prevented wheel lockup and gave significantly increased directional control, in exchange for a small loss of absolute stopping distance, provided a major benefit to overall vehicle performance. This is accomplished by using an ECU to sense individual wheel speeds, and then isolate and reduce brake fluid pressure to the wheel or wheels that are locking up. A schematic of such a feedback system is shown in Fig. 4.2, where the controller is an ECU, the controlled parameter is wheel cylinder pressure (via electrical solenoid valves), and the feedback elements are individual electronic wheel speed sensors (WSS). The WSS signals are typically generated via a pickup coil mounted adjacent to a toothed ring at each controlled wheel, where the pickup coil generates a varying voltage output proportional to the amplitude and frequency of the magnetic flux change as the ring teeth pass by it.

By monitoring the frequency output of each WSS, the ECU can decide if an individual wheel slip exceeds a desired threshold.[1] When such a threshold is exceeded at a particular wheel, the ECU directs the hydraulic control unit to isolate that wheel and reduce hydraulic pressure at that wheel, so that the wheel can resume rotation. Once the wheel is again rotating at about optimum slip (assuming the brakes are still applied) pressure is reapplied to that particular wheel. Typically, each wheel control circuit is called a channel and the hydraulic control unit is typically called a hydraulic modulator. Hydraulic modulators typically include three functions for each controlled wheel circuit: isolation, pressure-dump, and pressure-reapply. This control sequence causes a pulsed apply/release/apply[2] as ABS is controlling a wheel in an emergency stop, often up to ten times per second.[3]

Because of practical slip-threshold tradeoffs, ABS equipped vehicles may show a slightly increased stopping distance, but a marked increase in track control over the

[1]Usually a rate of wheel speed deceleration exceeding 1 *G*, or −21.95 mph/s (−35.33 kph/s).

[2]Often called *pumping* the brakes. However, drivers can only pump all circuits equally, whereas ABS systems can modulate individual wheel channel pressures many times a second when activated.

[3]Since this is faster and more precise than almost any driver can modulate brake channel pressures, and modulation can be selectively applied to individual wheel channels, drivers of ABS-equipped vehicles are instructed to never pump antilock brakes. Instead, drivers are instructed to apply firm and continuous pressure to the brake pedal to activate braking action and achieve optimum braking efficiency.

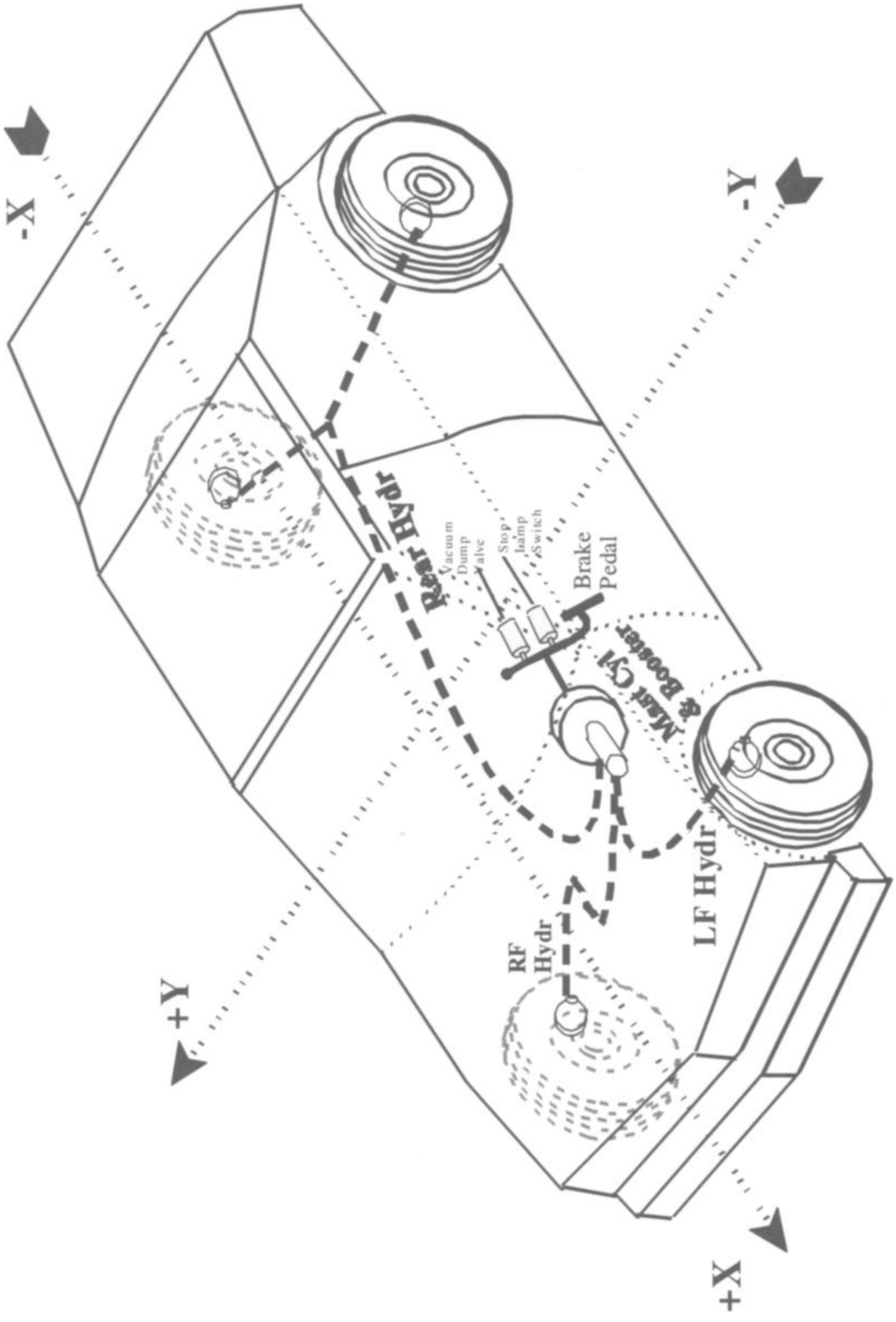


FIG. 4.1—Foundation brake system with planar SAE J211/J670e axes superimposed.

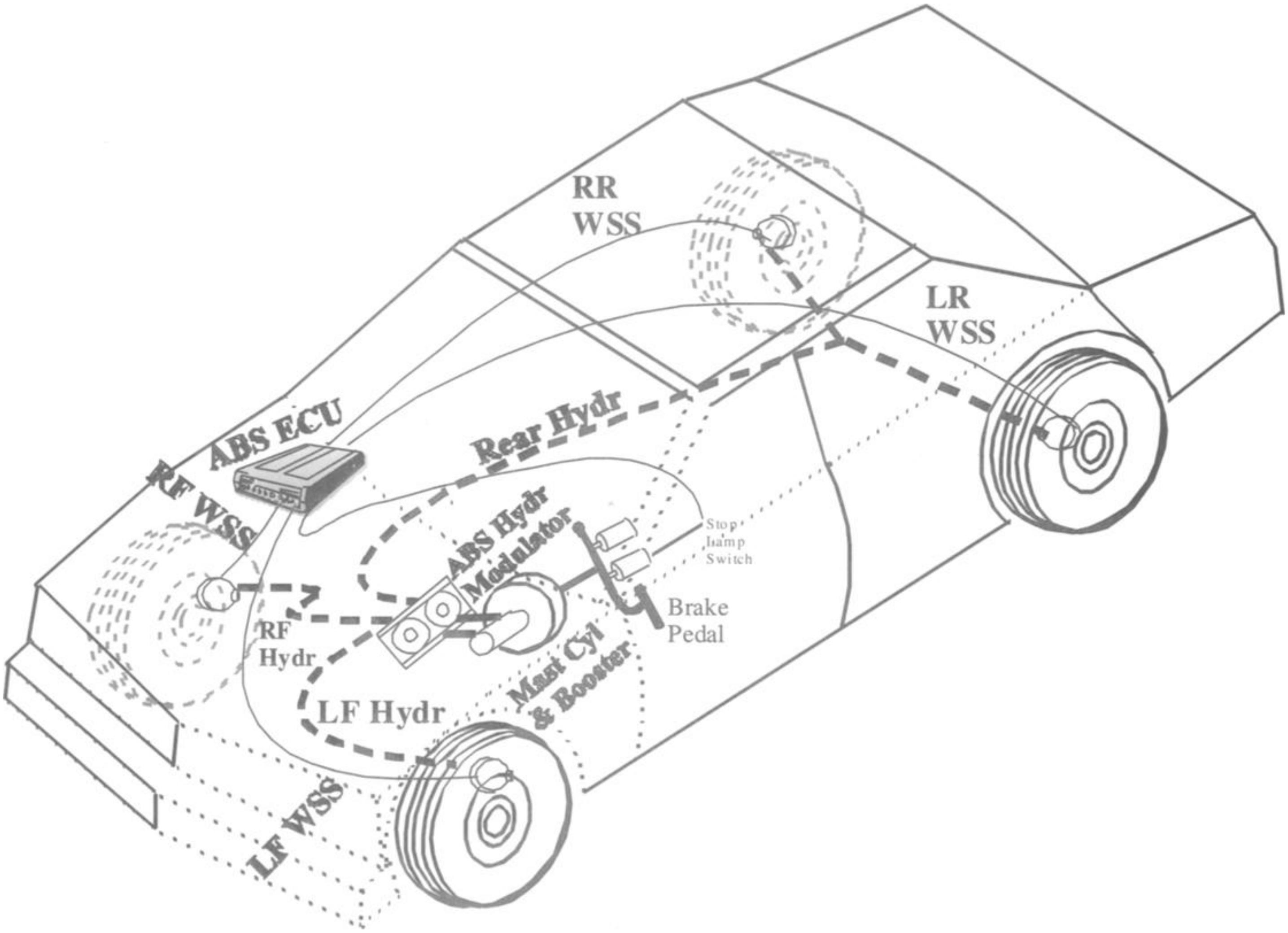


FIG. 4.2—Basic ABS schematic showing ECU, individual wheel speed sensors, and hydraulic modulator.

ensemble of many emergency braking situations. That tradeoff is deemed to be beneficial for the average driver on modern vehicles. Thus, the primary purpose of ABS is to preserve directional stability and allow the driver to continue steering during emergency braking, with an acceptable tradeoff of slightly longer stopping distance. Also, because wheel slip is limited with ABS vehicles, hard braking stops will not produce typical tire scrub artifacts on road surfaces, thus, complicating traditional accident reconstruction methods. When ABS is not activated, the foundation brakes operate normally; thus, normal stops are unaffected by ABS.

4.3 TRACTION CONTROL SYSTEMS

In the past few years, selected manufacturers have introduced systems that add traction and tracking control functions during acceleration as well as braking. ABS releases the brakes momentarily whenever wheel speed sensors indicate a locked wheel during braking, whereas traction control applies the brakes momentarily to one of the drive wheels whenever the wheel speed sensors indicates a wheel is going faster than the others during acceleration. Figure 4.3 shows a schematic of a basic TCS (traction control system) architecture. Note that the TCS is designed to operate only in the engine-acceleration mode, and its function is suspended if the operator applies the brake.

Some TCS systems also have the capability to also reduce engine power via electronic control of fuel injectors and/or spark timing. This is accomplished via bidirectional communications between the TCS ECU and the PCM.

4.4 COMBINED ABS AND TCS

Since the primary function of both TCS and ABS is control of a wheel whose speed significantly varies from the averaged speed of the other wheels (+ for TCS, – for ABS), where both features are incorporated in a vehicle, these functions are usually combined into one hydraulic control unit, sharing a common ECU. Figure 4.4 shows such a combined system architecture, with its combined ABS/TCS ECU. The ob-

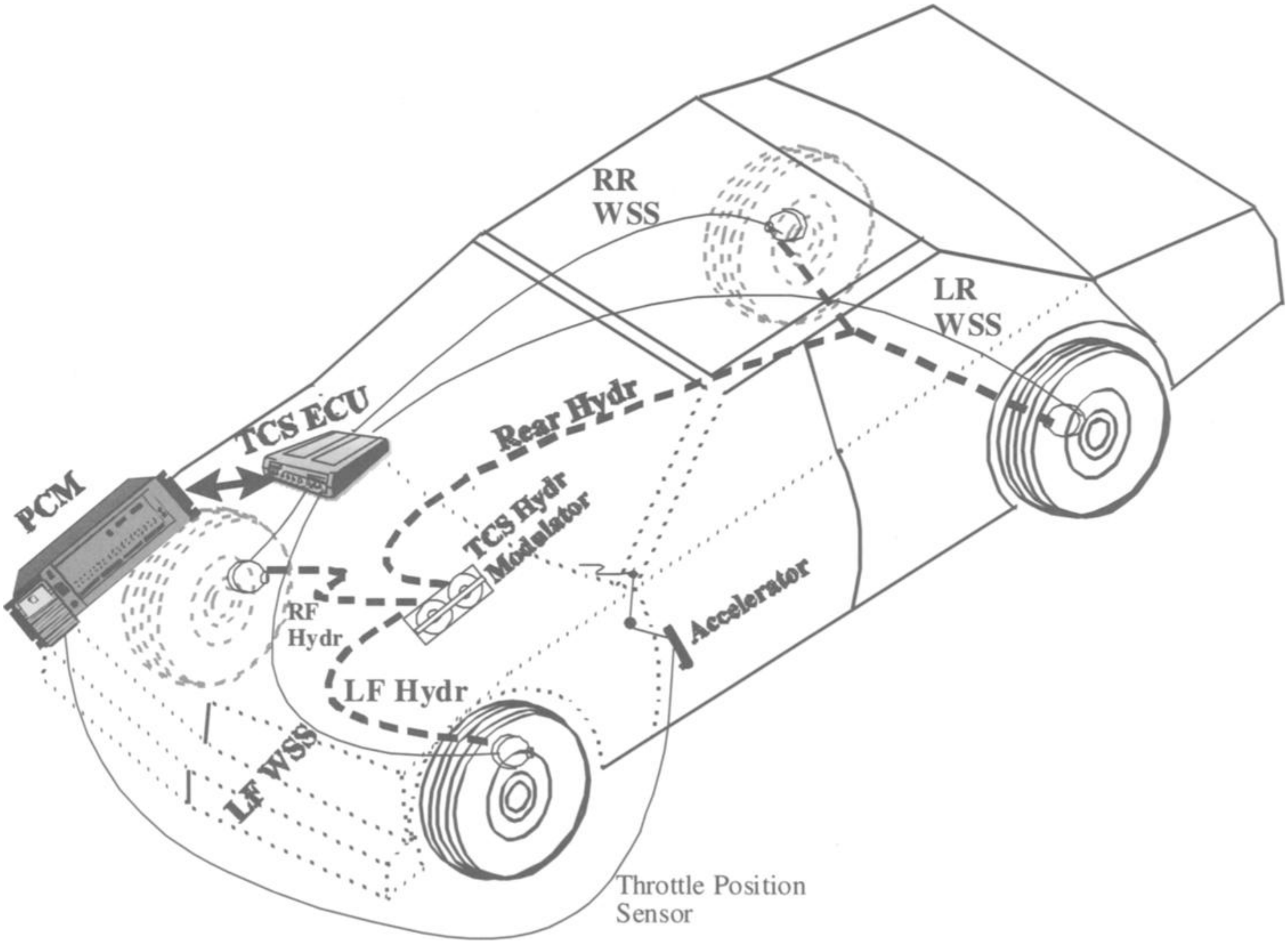


FIG. 4.3—Basic TCS schematic showing ECU, individual wheel speed sensors, hydraulic control and inter-PCM-TCS communications.

jective of both ABS and TCS is for them to operate transparently to the consumer operator so as to provide enhanced vehicle tracking stability under both braking and acceleration under adverse road surface conditions. This feature provides the ordinary driver with advanced tracking stability that was previously accomplished only by skilled racing and police drivers.

Thus, for combined ABS/TCS ECUs with the brake applied in ABS modes, if the speed of one wheel drops significantly compared with the other wheels, the brake pressure on that wheel is momentarily reduced (using isolation and dump valves) to stop the wheel from locking, and it is reapplied (using a motor/pump) when the wheel speed is near the average of the other wheel speeds. With no brake applied and under acceleration in TCS modes, if the speed of one wheel increases significantly compared to the other wheels, that wheel brake is momentarily applied to reduce that wheel speed (and with differential systems to redistribute traction power to the opposite wheel). Braking is removed when that wheel speed returns to near the average of the other wheel speeds.

Given that ABS, TCS, and ABS/TCS systems variously monitor parameters such as wheel speeds, brake application, accelerator application, etc. for normal operation, there is an obvious capability to save them in event triggered snapshot/freeze frames. These parameters can indicate critical aspects of operator-vehicle interaction and, thus, become an important element of the analysis of post-crash vehicle data.

4.4 COMPONENTS OF ABS/TCS UNITS

4.4.1 Common Components

All ABS-equipped vehicles have certain common components. These consist of an electronic control unit (ECU), one or more hydraulic modulator assemblies, one or more wheel speed sensors, and a wiring harness. The ABS system is transparent to the operator in normal operation, except for the (ABS) malfunction indicator lamp (MIL) in the instrument cluster. The ABS MIL is normally activated during key-

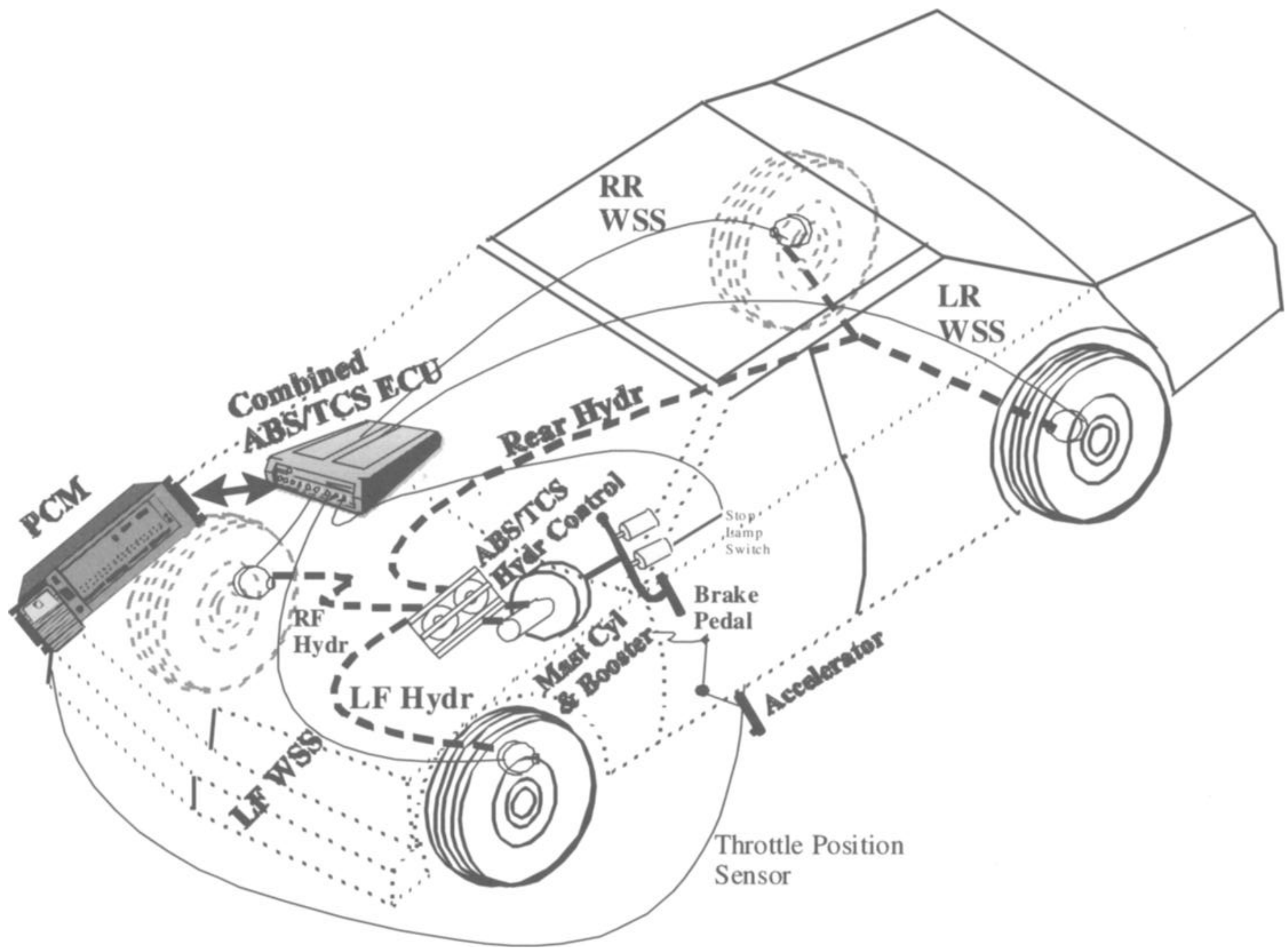


FIG. 4.4—Basic combined ABS/TCS schematic showing ABS/TCS ECU, individual wheel speed sensors, hydraulic control, and inter-PCM-ABS/TCS communications.

on diagnostic checks and remains off unless a system problem is detected.[4] In general, each channel operates with a dedicated wheel sensor circuit, hydraulic modulator subassembly, and sense/control portion of the ECU.

4.4.2 Wheel Sensors

Wheel sensors are the key components of both ABS and TCS systems. In order to determine vehicle wheel speeds, a wheel speed sensor (WSS) is placed on each wheel. Figure 4.5 shows a wheel speed sensor using an electrical coil to detect a change in the magnetic field of its magnetic core as a toothed wheel attached to the brake disk/drum rotates past it. As the teeth pass by the pickup core, a sinusoidal pulse train is generated with a frequency proportional to the speed of the wheel. This generated frequency is directly proportional to wheel revolutions/time and is said to be an analog of the wheel ground speed (at the circumference of the tire). Scaling arithmetic in the ECU microprocessor software is used to convert the input frequency analog to commonly understood units of ground speed (mph or kph). That wheel pulse train is monitored by the ABS/TCS ECU, which compares it to the speeds (frequencies) of the other wheels in order to determine individual wheel slip.

4.4.3 Pumps, Valves, Accumulators, and Motors

ABS and TCS hydraulic control units (HCUs) contain pumps, valves, accumulators, and motors that perform the ECU commanded functions for system operation. Most HCUs are relatively insulated from crash damage, but a few are located in the frontal crush zone, like the front wheel speed sensors. Since our purpose here is to focus on the sources of crash related data we will skip a discussion of HCU internal hydraulic function and close by observing that when an electro-hydraulic DTC is detected and saves a freeze frame for any reason, it can add intelligence to the crash investigation.

[4]The ABS MIL is usually colored amber, indicating a problem with an auxiliary safety system in the vehicle. The foundation brake MIL is colored red, indicating a problem with the primary foundation brake system (red being considered a more severe alert to the operator).

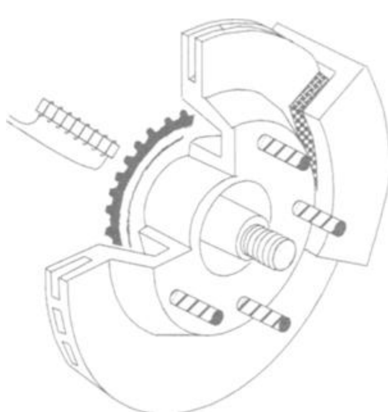


FIG. 4.5—Wheel speed sensor on a disk brake that uses variable reluctance magnetic pickup.

4.4.4 ABS and TCS ECUs

Similarly, most ABS and TCS ECUs are relatively insulated from crash damage. Thus, it is often the case that crash damage to a wheel sensor, causing a DTC and a snapshot/freeze frame, is available after a crash.

In order to interrogate an ABS or TCS ECU and prevent alteration of any data in the subject units when a vehicle is repowered, subject units are usually interrogated out of the subject vehicle. This prevents adding DTCs for conditions that may have been introduced in the towing after a crash and while battery power was lost. In certain ECUs, freeze frame data from an existing DTC can be overwritten by the detection and saving of a new DTC. Thus, a crash-event DTC (and its snapshot/freeze frame) could be "pushed down" and the snapshot/freeze frame overwritten to reflect the conditions at the last DTC (i.e., a DTC generated after the crash, and possibly reflecting post-crash damage). When such a unit is interrogated, the test bed (either another vehicle or a laboratory fixture) is always first exercised with an exemplary unit to prove that the test bed will not add to, or alter, the subject unit data contents.

4.5 ABS/TCS DIAGNOSTICS AND DATA EXAMPLE

4.5.1 Format and Scaling of the Freeze Frame Data

For various versions of ABS/TCS systems as applied to different model vehicles, there are various versions of the content, format, and scaling of its crash-event snapshot/freeze frame data. Since each version of such data has a specific format and mathematical interpretation scheme, a hexadecimal list with no translation of its contents is not very useful.

The content and interpretation format(s) of various data fields of EEPROM data are often summarized in a worksheet similar in purpose to the SRS EEPROM worksheet. Such worksheets are derived from multiple engineering specifications, software listings, and electrical schematics. These documents actually define how the ECU operates and the content, format, and scale factors with which the ECU records data in EEPROM or flash memory.[5]

To illustrate such a data scheme and its interpretation process, a fragment of hypothetical example crash event data is shown below, with its worksheet interpretation. Such data would have been obtained by a vehicle download as shown in Fig. 4.6. In Fig. 4.6, the data inset shows the hexadecimal data used in the example worksheet below.

[5]These engineering specifications, software listings, and electrical schematics are universally considered to be manufacturer-proprietary and are usually available only under confidential non-disclosure orders.

Excerpt of Hypothetical ABS EEPROM Data (Hex Data Paragraph and Interpretation)

Original Data Format

0000	**5D 84**	**11 01**	**84 0C**	**87 20**
0008	**0C C2**	**2D 01**	**A7 0A**	**BA 13**
0010	**25 01**	**01 A6**	**FF FF**	**FF FF**
0018	**FF FF**	**FF 35**	**4A 21**	**0B 0A**

HEX DATA BYTE ADDR	DATA - BYTE VALUE - HEX	DEC	BINARY	INTERPRETED MEANING & ENCODING EVALUATION, HYP EXAMPLE
0000:	5D	93	0101 1101	SOFTW IDENT version,level, Version 5, Level D
0001:	84	132	1000 0100	SOFTW DATE HI yr, month, {199}8, April
0002:	11	17	0001 0001	SOFTW DATE LO day, 17^{th} day
0003:	01	01	0000 0001	# ABS Stops, Counter, HiByte}
0004:	84	132	1000 0100	# ABS Stops, Counter, LoByte} 0184 hex ==> 388 dec
0005:	0C	12	0000 1100	# Global Ign Cycles, Ctr, HiByte}
0006:	87	167	1000 0111	# Global Ign Cycles, Ctr, LoByte} 0C87 hex ==> 3207 dec
0007:	20	32	0010 0000	Global History DTCs mask: 0, 1, 2, 3, 4, 5, 6, 7
0008:	0C	12	0000 1100	Global History DTCs mask: 8, 9, A, B, C, D, E, F
0009:	C2	194	1100 0010	First DTC = C, 2^{nd} DTC = 2
000A:	2D	45	0010 1101	Last-1 DTC = 2, Last DTC = D
000B:	01	01	0000 0001	# Ign cycles @ first DTC, HiByte }
000C:	A7	167	1010 0111	# Ign cycles @ first DTC, LoByte } 01A7 hex ==> 423 dec
000D:	0A	10	0000 1010	# Ign cycles @ last DTC, HiByte}
000E:	BA	186	1011 1010	# Ign cycles @ last DTC, LoByte} 0ABA hex ==> 2746 dec
000F:	13	19	0001 0011	Averaged WSS @ first failure ==> 19 MPH (30.6 KPH)
0010:	25	37	0010 0101	Averaged WSS @ last failure ==> 37 MPH (59.6 KPH)
0011:	01	01	0000 0001	# Resets since factory [does not reset any Ign Counter]
0012:	01	01	0000 0001	# Ign cycles @ last Reset, HiByte}
0013:	A6	166	1010 0110	# Ign cycles @ last Reset, LoByte} 01A6 hex ==> 422 dec
0014:	FF	255	1111 1111	Factory Data
0015:	FF	255	1111 1111	Factory Data
0016:	FF	255	1111 1111	Factory Data
0017:	FF	255	1111 1111	Factory Data
0018:	FF	255	1111 1111	Factory Data
0019:	FF	255	1111 1111	Factory Data
001A:	FF	255	1111 1111	Factory Data
001B:	35	53	0011 0101	Engine Option 5.3 Liter
001C:	4A	74	0100 1010	Transmission option, 4 speed Automatic
001D:	21	33	0010 0001	Axle ratio, 3.3:1
001E:	0B	11	0000 1011	Front tire size code
001F:	0A	10	0000 1010	Rear tire size code

From the above example, we can see that:

1. The unit under examination incorporates software Version 5, Level D, which was released on the 17th day of April 1998.
2. There are 15 possible DTCs, identified by their hex symbols, 1 to 9 and A to F, with 0 not used.
3. The ignition cycle counter and averaged wheel sensor speeds (WSS) are saved as freeze frame data for the first and last DTC recorded (in the current record after the last system reset).
4. There was one reset at ignition cycle 422.
5. A new DTC was saved on the very first cycle after reset (423), DTC "C," and there was an average wheel speed of 19 mph.
6. The last DTC, "D," was saved at ignition cycle 2746, and the average WSS was 37 mph at that time. Since the total ignition cycle count is now 3207, we know that there is no relationship between the last saved WSS and any event in the current (or current −1) ignition cycles. However, if the Last −1 cycle was also the crash cycle,[6] then we may have a good indication of a minimum speed of impact.[7] This can be compared with the cumulative Delta V saved in the SRS ECU to determine if the SRS recorded deceleration was final, or if the vehicle proceeded on after air bag deployment.
7. One can check the tire sizes to see if they match the EEPROM data. Incorrect tire sizes can contribute to control problems.
8. In this history cycle (after the reset), we know that there were only three DTCs saved. Note how the second DTC, "2" (address $0009) is also the Last −1 DTC (address $000A).

[6] Sometimes saved in the SRS ECU and/or EDR.

[7] Since the ABS ECU may not recognize the DTC until some time into the impact, and then record speed, the vehicle may have slowed from its pre-impact speed.

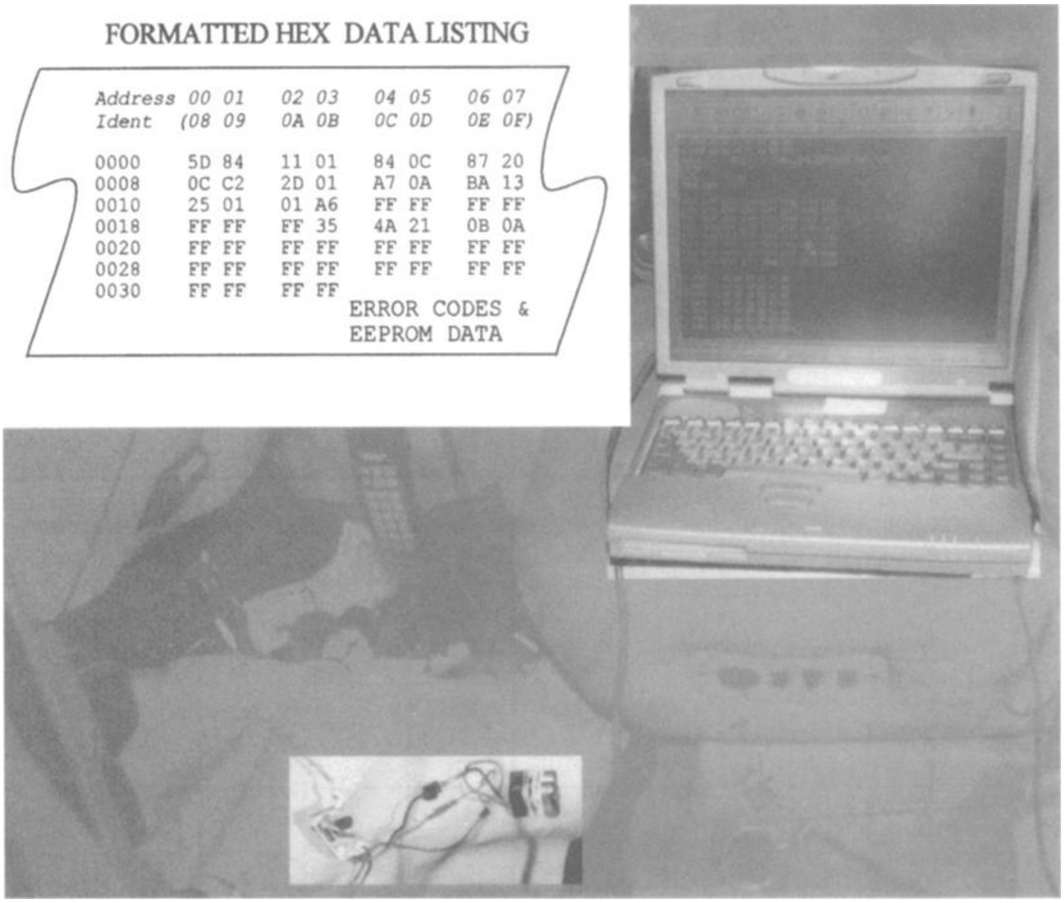


FIG. 4.6—Laptop computer and data interface operating as a scanner to download and record ABS EEPROM data from a 1995 domestic pickup truck. Data shown in the inset is from the example of Section 4.5.1.

4.5.2 Freeze Frame Parameters That Can Be Associated with Crash Events

Below is a representative list of parameters that can be saved in a freeze frame associated with a crash-related ABS/ETR event. Some parameters will obviously be saved in the ABS ECU, and others may be saved elsewhere, depending on design complexity and the level of systems integration.

- Wheel Speed
- Active Faults
- History Faults
- Brake Switch Status
- Number of ABS Occurrences
- Number of Ignition Cycles Before First Fault
- Number of Ignition Cycles After First Fault
- Warning Lamp Status
- Vehicle Speed
- Pump Motor
- Valve Relay
- Engine Torque
- Solenoids
- ABS State
- Engine Speed
- Tire Size

Examples of ABS/TCS freeze frame parameters useful in crash investigations are shown in Chapters 1, 6, and 7.

Finding Data in Post-Crash Vehicles and Deriving Useful Data Parameters

5

5.1 OBTAINING THE DATA VIA ON-VEHICLE DIAGNOSTIC PORTS OR INDIVIDUAL ECU UMBILICALS

WE HAVE ALREADY SEEN SEVERAL EXAMPLES of data download via on-vehicle diagnostic ports or individual ECU umbilicals. For some systems, after the scanner interface has connected via the specific network protocol, it is possible to download the entire EEPROM contents of a target ECU (given the right interrogation command codes). Such a download is shown in Fig. 3.18. In other systems, the target ECUs must be interrogated using an umbilical cable from the scanner directly to the ECU, or by inserting the ECU in a laboratory fixture. Such downloads are shown in Figs. 3.19 and 3.20.

Where multiple access means are possible, it is often useful to know that the data parameter lists obtained are equal (i.e., the same PIDs are listed in both devices), and that any value differences can be explained. One example of such a comparison is shown in Fig. 5.1, where freeze frame parameters listed for DTC P0230 are compared between a laptop/B&B AT12 display and the display on a GM/HP Tech 2. Note that the readings were taken at different times and different power-on cycles and so produced slightly different readings.

5.2 OBTAINING THE DATA IN ECUs AFFECTED BY CRASH AND FIRE DAMAGE

After a crash event, it is often impossible or unwise to attempt to power the normal vehicle systems. In such cases there are two possible approaches:

1. The target ECU can be separately powered through the fuseblock and then read via the vehicle network diagnostic port.
2. The ECU can be interrogated via an umbilical connection, which isolates the target ECU from the vehicle and performs the download via a test set or laboratory breadboard. An example umbilical connection downloading hexadecimal EEPROM data from a partially salvaged vehicle is shown in Fig. 5.2.

In the event that it is decided it is better to remove the ECU and interrogate it later in a laboratory setting, care must be observed in its removal. For instance, integrated-sensor SRS ECUs are mounting torque sensitive. That is because the crash pulse must be transmitted from the vehicle body through the mountings to the internal accelerometer sensors. Thus, to ensure that the data that will be later read from the ECU represents the product of a proper pulse transmission shock path, it is necessary to check the mounting bolt torques of the SRS ECU. Alternatively, if the pulse-transmission shock-path is improper (e.g., mounting bolts too loose) the data in the ECU may not properly represent the data at that point on the vehicle chassis and may thus be incorrect with respect to the true vehicle crash pulse.

Confirmation of proper ECU mounting is done by measuring the tightening torques of the attaching bolts (Sturtevant-Richmont, undated; ASTM 1997).[1] The torques are best measured with a recording torque wrench that has a dial or electronic readout. An example of such a measurement for an SRS ECU is shown in Fig. 5.3. The same caution applies to external accelerometers used in certain ABS and TCS systems and distributed to external sensors.

A harder task is the recovery from submerged or fire-damaged vehicles. Figure 5.4 shows a mosaic of the careful steps required to recover EEPROM data from a severely fire-damaged vehicle. Panel A shows the vehicle as first viewed, with burnt components strapped onto the body shell laying over the SRS ECU. Panel B shows the SRS ECU identified in the debris before removal, including first measuring mounting bolt torques.[2] Panel C shows the SRS ECU after the burnt vehicle harness was separated from the SRS ECU. Note that despite the external fire damage, the burnt unit connector is quite usable. Panel D shows the burnt SRS ECU next to an exemplary unit that was interrogated before interrogating the burnt unit (to assure correct EEPROM interrogation operations). Panel E shows the EEPROM download from the burnt unit using the test umbilical connector to the burnt unit (shown at the top of Panel D).

5.3 FINDING OUT IF AN ECU HAS DATA IN EEPROM OR FLASH MEMORY

In some cases, the investigator is faced with the question of whether a subject ECU contains any EEPROM/flash memory data at all. While some earlier ECUs used discrete EEPROM devices, almost every current design utilizes microprocessor/microcontroller devices that incorporate

[1]The essence of mounting bolt torque measurement is to measure the torques to which the bolts were fastened at the time of assembly. To do this one must measure the continuing tightening torque just after passing the breakaway friction built up from long-term fixed-position bolt corrosion, etc. If an attempt is made to measure the "loosening torque" one will have measured the breakaway friction and then, because the bolt is being loosened, will have lost forever the continuing tightening torques for the ECU bolts.

[2]The reader must recognize that bolt torques measured after the mounting point has been subjected to intense heat may not reflect the original mounting conditions because of the effects of the heat on the bolts. In the example above, the torques were measured in an abundance of caution, and it was later found that the ECU diagnostics functioned correctly. Thus, the internal electrical solder connections were functionally intact, and, thus, the heat at that location was not as intense as initial visual appearances indicated.


```
 File  Page  Log  Item  Options  Help |  Log:               Cfg:
+------------------------------ Freeze Frame Data ------------------------------+
|                                                                                |
|                        DTC that caused last Freeze Frame:                      |
|                   P0230 FUEL PUMP PRIMARY CIRCUIT MALFUNCTION                  |
|                                                                                |
|--------------------------------------------------------------------------------|
|          Fuel System 1: OL - 1          |      FF Not Run Counter: 0           |
|  Calculated Load Value: 0.00 %          | »  Barometric Pressure: 70.3 inHg    |
|    Engine Coolant Temp: -38 °F          |                                      |
|      STerm Fuel Trim B1: -0.8 %         |                                      |
|      LTerm Fuel Trim B1: -0.8 %         |                                      |
|                     MAP:  3.0 in. Hg    |                                      |
|           Engine Speed:      0 RPM      |                                      |
|          Vehicle Speed:    0 MPH        |                                      |
|       MAF Air Flow Rate: 0.00 lb/min    |                                      |
|        Throttle Pos Sen:  0.8 %         |                                      |
|    Inj Pulse Width Cyl1: 0.00 ms        |                                      |
|          Air Fuel Ratio: 11.7 :1        |                                      |
|  Odometer-1st Code Set:       0 Miles   |                                      |
| Odometer-last cde clrd:       0 Miles   |                                      |
|    Freeze Frame Counter: 0              |                                      |
|                                         |                                      |
+-<INS>=DTC List----------- VIN: 2G4WY52M3X1498298 -----------------MIL OFF----+
          AutoTap 2.06b - B&B Electronics, Ottawa, IL - (c) 2000
```

Same Freeze Frame Record on GM Tech-2 Scanner =====>

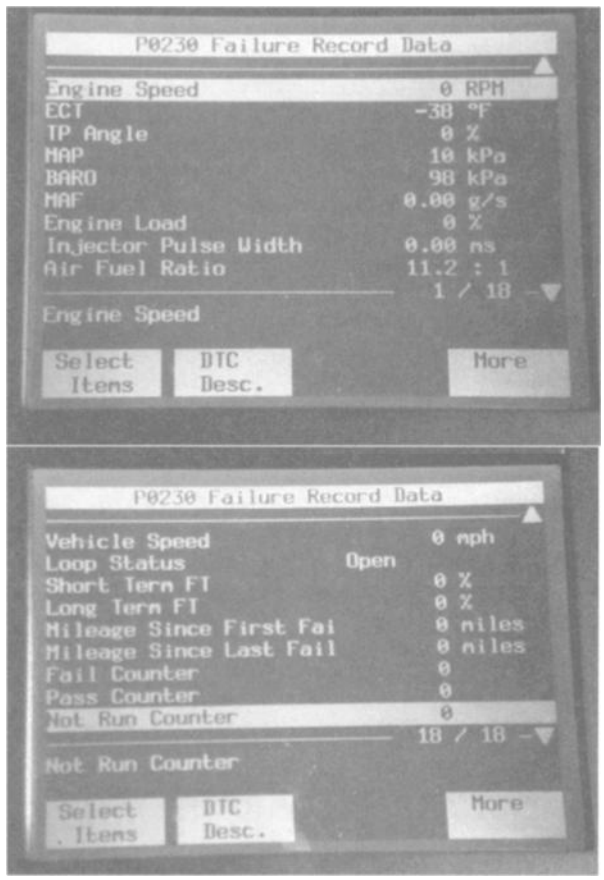


FIG. 5.1—Comparison of freeze frame parameters for DTC P0230 between B&B Electronics AutoTap 12 and a GM Tech 2 on a post collision vehicle. The figure shows that the parameter list is identical. Note that both scanners record that the engine coolant temperature is at −39°F, the lowest default value, indicating that the coolant sensor or its harness was damaged in the collision, while other readings vary because they are adaptive, and were taken at different times.

EEPROM/flash memory within the IC chip in the device package. When EEPROM/flash memory is incorporated within the IC chip in the device package, it is said to be embedded in that device.

In cases where the investigator is given no information from the ECU manufacturer, the search for EEPROM/flash memory begins with ECU cover removal and identification of the internal devices likely to have embedded EEPROM/flash memory. Often the internal devices are identified only with a logo. Examples of logos found on typical components in automotive ECUs are shown in Table 5.1. Once the device manufacturer is identified from its logo, product specifica-

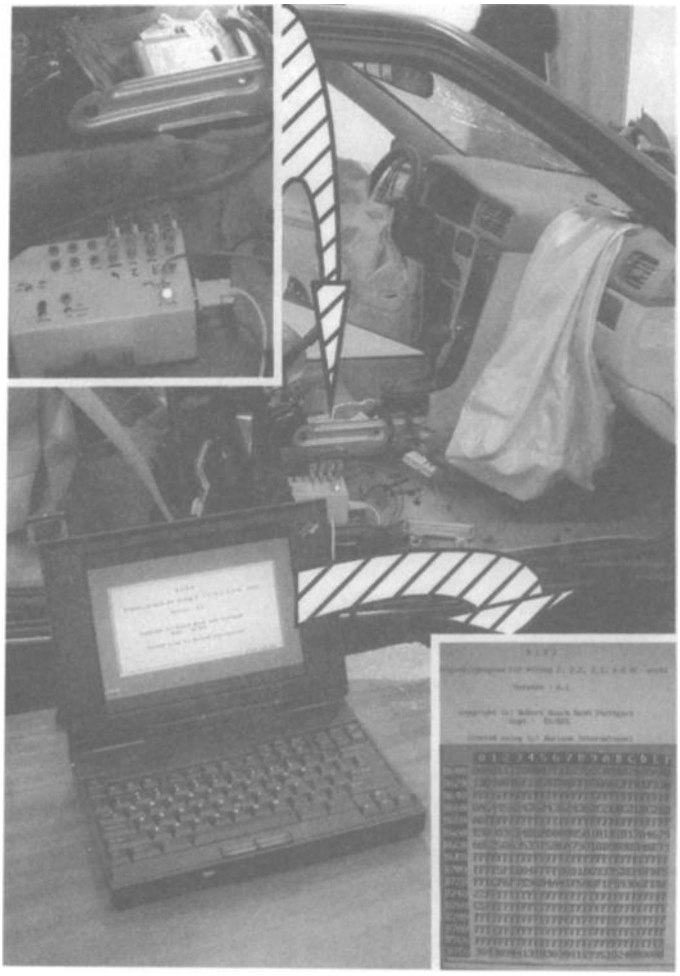


FIG. 5.2—Field download of SRS ECU EEPROM data using an interface and umbilical connection directly to the ECU, which avoids the damaged vehicle network in a partially salvaged vehicle.

tions corresponding to the part number (P/N) and version can usually be obtained from local sales offices or from extensive product listings located using most popular search engines on the internet.

5.4 IDENTIFYING ECU EEPROM/FLASH MEMORY INTERROGATION CODES

Assuming that we have determined if there is EEPROM (and, consequently, saved data) in a particular ECU, we are still faced with determining how to download that data for analysis. In most contemporary vehicles, 1996 and later, most of the on-board ECUs are accessed via the OBD-II connector. Many are on one of the networks specified in Chapter 1, Fig. 1.12. Each of the ECUs on a network has an individual address, and each also has individual communication mode commands to enable interrogation of its EEPROM. None of these are published, but there is a way to determine the initial access to an ECU.

Recall that all of the ECUs on an automotive network are autonomous. That means that any two or more ECUs, properly connected, will form a valid network. Recall also that the standard means of interrogating any ECU on a network is with an approved manufacturer or aftermarket scanner. The scanner, once it is properly connected, acts just like another ECU on the network; however, its command and communication set is solely oriented to interrogating (or controlling) a target ECU. Another tool that is available in the industry is a network analysis tool. These tools, normally used with a laptop computer, also connect to a network, and they have features that display and save network message traffic (in hexadecimal format). Thus, with such a tool one can see the exact format of communications between two ECUs on a network. Examples of two such network analysis tools are available from AVT and SET.[3]

If we create a special network as shown in Fig. 5.5,[4] we can isolate a specific ECU and the scanner that is interrogating it. If we then use a network analysis tool to monitor the communications between the specific ECU and the scanner that is interrogating it, we can record that network message traffic (in hexadecimal format) occurring on the 3-ECU special network. We can then learn the physical addresses and a subset of proper command modes that cause an ECU response.

We can learn this because we know the scanner input commands we initiated to cause any particular interrogation, and we can repeat these indefinitely. We can begin to associate known repetitive input commands with repetitive hexadecimal-encoded network message patterns. We can then remove the scanner to create a 2-ECU special network and interrogate that ECU with the learned hexadecimal-encoded network message pattern and replicate the original scanner input. In this manner, we can turn our network analysis tool into a substitute scanner. After we establish that capability, we can explore additional interrogation capabilities for that specific ECU.[5]

Figure 5.6 shows a SET/NETWAY network analysis tool monitoring Vetronix CDR communications with an SRS ECU in a laboratory breadboard (special network). The message traffic between the CDR and the ECU was captured and documented using the network analysis tool. This allowed us to learn the command set to the ECU, and its response, for a known command-query and ECU-response content. The network analysis tool was then used, with the CDR disconnected (but with the command-query content learned by monitoring the CDR communications) to properly interrogate that SRS ECU.

[3] See Appendix B.

[4] The special network shown in Fig. 5.5 is sometimes called a breadboard or test bed. Alternatively, one can disconnect nonpertinent ECUs from a vehicle network and accomplish the same electrical architecture.

[5] The science of learning true data content from repeated strings of encoded (encrypted) message traffic raw data is called *cryptoanalysis*. Modern cryptoanalysis techniques date from the 1930s with Polish, British, and American efforts to decode German, Japanese, and Russian encrypted messages intercepted via radio, cable, and telephone wiretaps. The success of these efforts was reported to make a great difference in WWII military campaigns in both the European and Pacific theaters (Budiansky 2000; Kozaczuk, undated; Sale, undated; Whitlock 1995).

FIG. 5.3—Checking attaching bolt-tightening torques before SRS ECU removal.

5.5 DERIVING RESTRAINT SYSTEM TIMING RESPONSE FROM CRASH PARAMETERS

One of the most significant challenges facing the accident investigator is the absence of information or parameters needed to complete a full analysis. Information can be missing because:

- Certain saved ECU data have not been read and/or interpreted.
- The saved parameters do not contain the specific parameter needed.

We have already shown in Chapter 2 how a total cumulative Delta V can be calculated by knowing a_{peak} and t_{pulse} of a haversine crash waveform, and a complete case study will be shown in Chapter 6. Other case studies in Chapter 6 will show how impact cumulative Delta V can be determined from a summation of incremental time slice Delta Vs.

Here in Chapter 5 we will show how the important subcomponents of a total t_{pulse} can be computed from related parameters and specification information in a distributed sensor system. Those sub-components of the total t_{pulse} will identify the time from impact to air bag fire signal, and ultimately the safety performance of the restraints system(s).

5.5.1 Determining Air Bag Deployment Timing in a Distributed Sensor System

In distributed sensor systems, the air bag squibs are fired by the completion of a series circuit as shown in Fig. 3.4 and described in Section 3.3.2. The ECU in these systems can easily record the time after first sensor close until the second sensor closes. The most usual sequence in these cases is for the arming sensor to close, followed by one (or both) discriminating sensors, to complete the series circuit and create a closure time overlap condition. Since the ECU can only

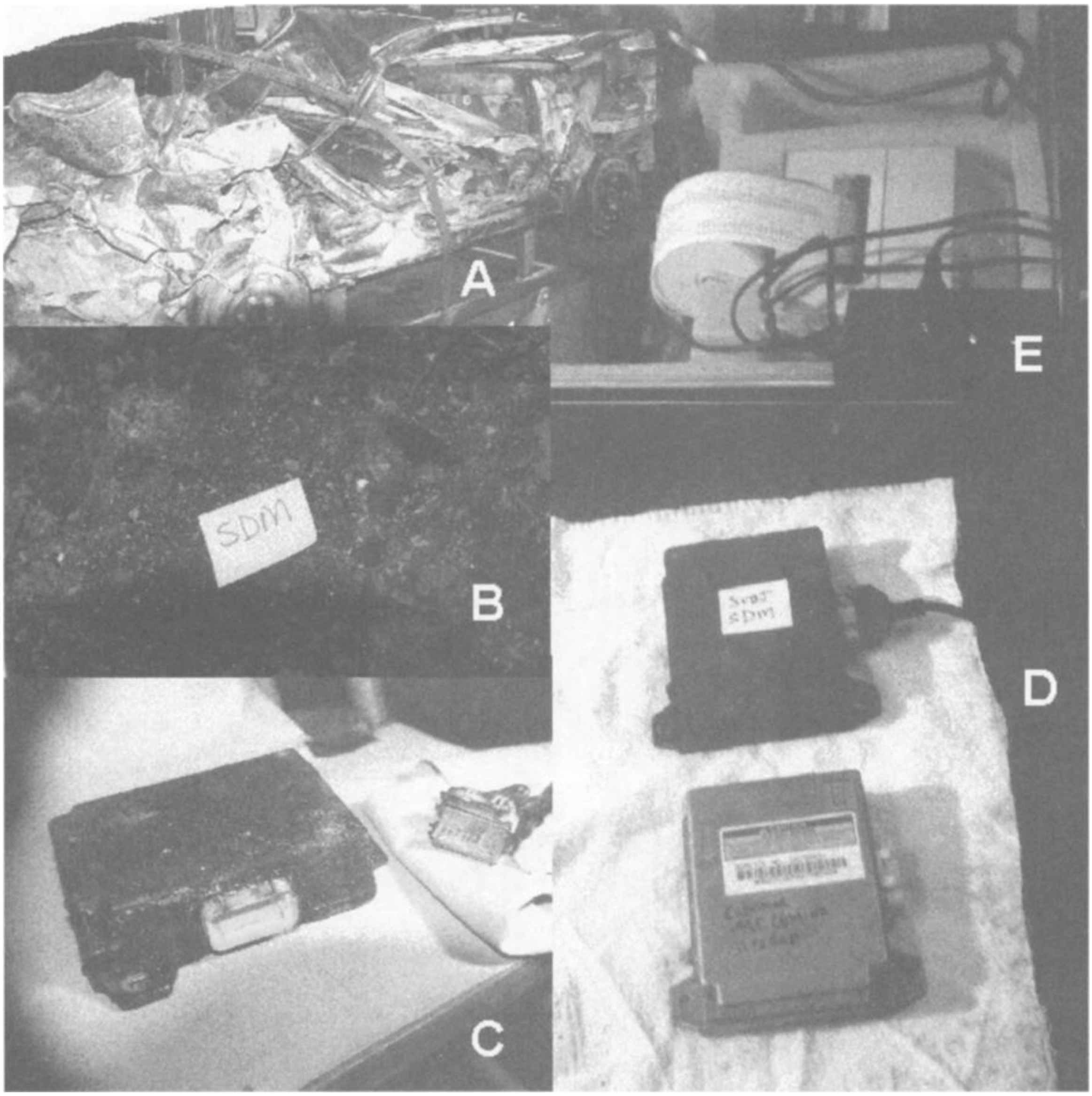


FIG. 5.4—Mosaic showing scanner retrieval of crash data from burnt vehicle after recovering partially burned SRS ECU.

detect the state (and change in state) of each of the sensor switches, the most typical parameter recorded is the time between closure of the arming sensor and the overlapping closure of the first discriminating sensor. In our example below, we shall assume that the ECU recorded 61 ms as the time between closure of the arming sensor until the overlapping closure of the first discriminating sensor. Yet unknown is the first portion, the time from first contact (impact) until closure of the arming sensor.

The yet unknown arming sensor timing (the first time portion) can be determined by analysis of the intersection of two simultaneous time functions. There are two methods of determining the first of the simultaneous time functions—the vehicle velocity loss after impact. One method of approximating the time function of vehicle velocity loss in an impact uses reconstruction analysis and simulation programs such as CRASH and SMAC. These tools can provide a first-pass approximation of the deceleration and velocity functions of a subject crash. The second method of determining the time function of vehicle velocity loss in an impact utilizes data from exemplary test crashes. Assuming that one can find one or more comparable vehicle and comparable velocity test crashes, one can use the recorded deceleration and velocity functions to bracket the likely deceleration and velocity functions of the subject vehicle (in a manner similar to reconstruction analysis). Within limits, such comparable data can also be scaled more closely to approximate the subject crash.

An example of such a post-impact velocity loss is shown in Fig. 5.7. The velocity profiles shown in Fig. 5.7 are a typical low-speed soft-impact collision such as a pole impact or heavy truck underride, and not the orderly and symmetric haversine described in Chapter 2.

TABLE 5.1

Logo Symbol	Logo Complete	Manufacturer Mail Address Info	Web Address Info
TM	BOSCH TM	Bosh Germany	
TM	CIRRUS LOGIC® TM		
CRYSTAL TM	CRYSTAL A Cirrus Logic Company TM	Crystal Semiconductor Corporation P.O. Box 17847 Austin, TX 78760 (512) 445-7222 FAX: (512) 445-7581	www.crystal.com
TM	HITACHI® TM	Hitachi America, Ltd, Semiconductor Div. 2210 O'Toole Ave. San Jose, CA 95131 408-435-2748	
intel® TM		Intel Corp Bowers Ave Sunnyvale, CA	
TM	MOTOROLA TM	Motorola Semiconductor Inc Dobson Mesa, AZ	
TM	TEXAS INSTRUMENTS TM	Texas Instruments Inc. Technical Pubs Manager, MS 702 P.O. Box 1443 Houston, TX 77251-1443 (214) 644-5580	
TM	THOMSON-CSF TM		
TM	XICOR TM	Xicor, Inc. 1511 Buckeye Drive Milpitas, CA 95035 (408) 432-8888	www.xicor.com

NOTE: All logos and marks shown above in Table 5.1 are the registered trademarks of the corporations and/or companies shown adjacent to the respective registered trademarks and are used here with permission.

In Fig. 5.7, pre-impact velocity is that velocity existing before impact at 0 ms (0 ms = t_0), and this velocity is shown as a heavy line (A). The laws of motion and reaction defining the velocity change to a fixed mass (a vehicle), in response to an input force, have already been described in Chapter 2. If we consider our input force to be defined as our impact force, and consider the mass to be at an initially fixed zero velocity, we can calculate a velocity increase of our mass (a vehicle) in this very traditional manner. This velocity increase is shown as Trace (B) on Fig. 5.7. Curve **B** is often described as the cumulative Delta V (accruing from the impact force).

However, this cumulative Delta V is the exact mirror image of the velocity decrease (deceleration) that would be imparted to an already moving vehicle (at $V_{\text{pre-impact}}$) by application of the very same impact force. So, if we subtract Trace (B) from our approach velocity, $V_{\text{pre-impact}}$ (A), the result is Trace (C), which represents our vehicle deceleration in response to an impact force.[6]

Thus, we have shown how, after impact (t_0), at an initial velocity, $V_{\text{pre-impact}}$, the vehicle starts decelerating in response to the impact force. Now let us examine how the cumulative Delta V is used to detect a crash condition, or more specifically, how an electromechanical sensor, responding to the

[6]The magnitude of velocity subtracted from the original $V_{\text{pre-impact}}$ can be thought of as the complement of the originally calculated velocity increase.

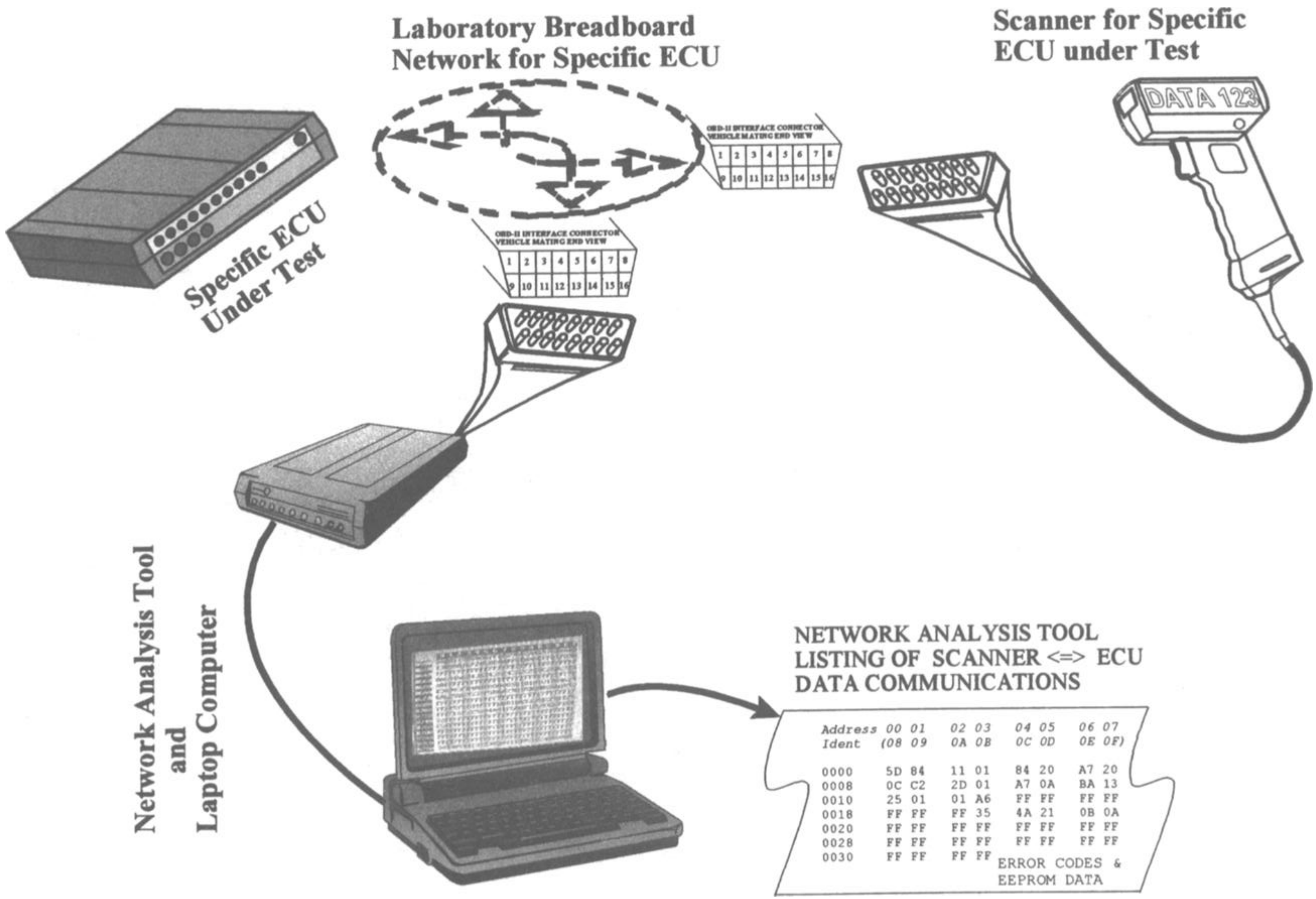


FIG. 5.5—Using a network analysis monitor to learn specific ECU communication protocols from a standard diagnostic scanner.

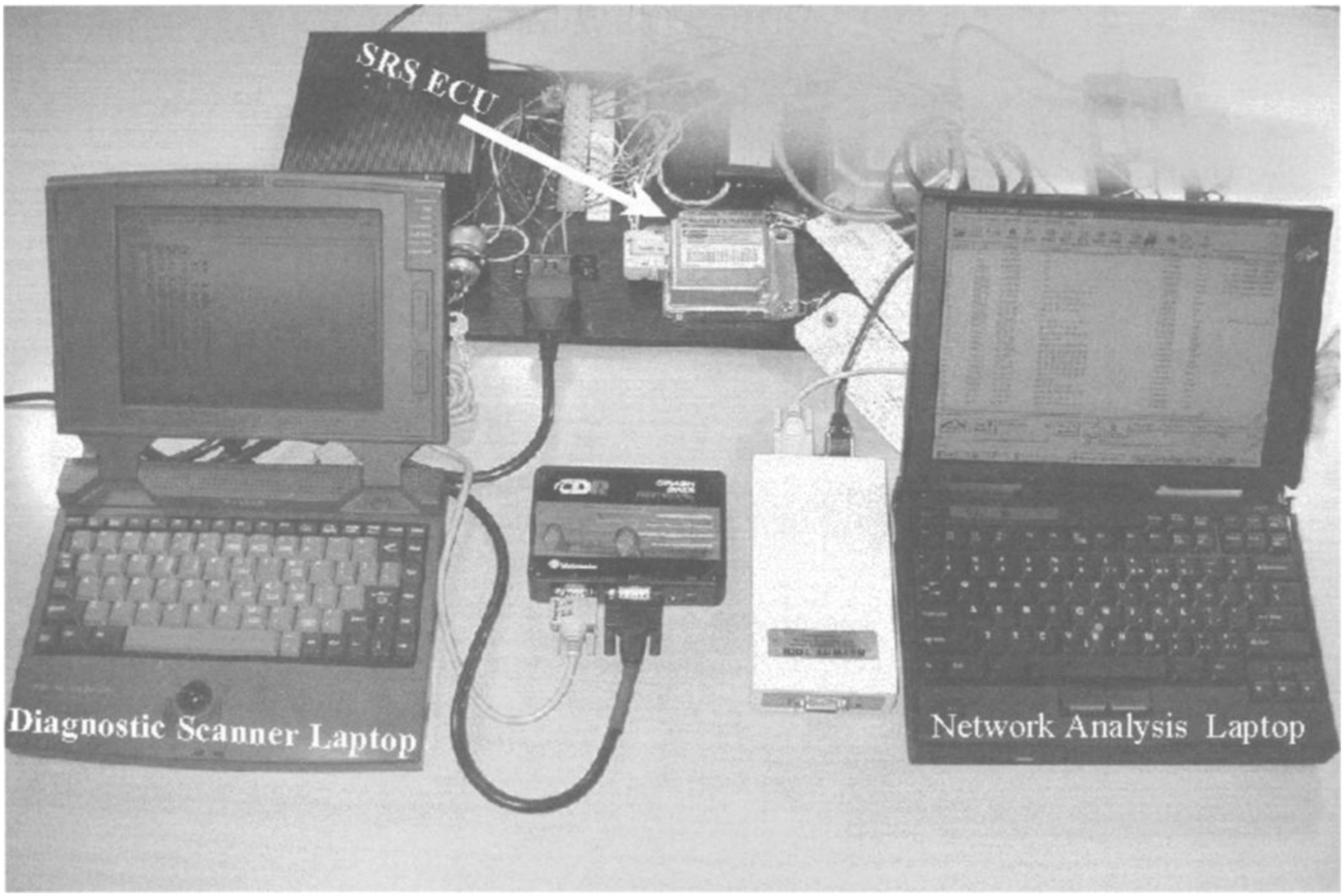


FIG. 5.6—SET/Netway network analysis tool monitoring Vetronix CDR communications to SRS ECU in ASA laboratory breadboard.

acceleration created by such a velocity loss, indicates this condition by closing a switch.[7]

In actual applications, the vehicle velocity loss is transmitted through its frame to the sensor location, where it produces an acceleration (deceleration) of the sensor frame, causing a displacement of the mass in a manner to close the switch.

5.5.2. First Pass Analysis for Determining Restraint System Timing Response

Let us continue with our analysis using the following assumptions:

- We have a distributed sensor system with a distributed sensor SRS ECU. In these systems, the time at which the air bag would have been commanded to fire is determined by completion of the series circuit described in Fig. 3.4, which is also the start of sensor overlap time.
- The distributed sensor SRS ECU records the time interval between the first sensor closure and the second sensor closure.
- The distributed sensor SRS ECU records the time duration when both the arming and the discriminating sensors are closed, and that is called sensor overlap time.
- For our example, the crash record data in the SRS ECU show that the time between the first sensor closure (arming) and the second sensor closure (discriminating) is 61 ms.[8]
- The crash velocity changes of Fig. 5.7 apply to this crash impact. Figure 5.7 shows the pre-impact velocity (A), the cumulative Delta V (B), and the deceleration (C).

Our assignment in this first pass analysis is to determine the time after impact (t_0) at which the air bag would have been commanded to fire. This happens when the series circuit described in Fig. 3.4 is completed. The time period we are after is the sum of the time from impact until the arming sensor closes plus the time until either of the discriminating sensors closes.

Our analysis of the crash record data in the SRS ECU shows that the time between the first sensor closure (arming) and the second sensor closure (discriminating) is 61 ms. To

[7]Recall from Chapter 3 (Figs. 3.4 and 3.9 to 3.11), how each electromechanical sensor switch closure completes its part of the series circuit for air bag deployment.

[8]61 ms is much greater than the time that would be experienced in a 30 mph (48.3 kph) frontal barrier collision. However, 61 ms is well within the interval times experienced in a lower speed pole impact or underride collisions.

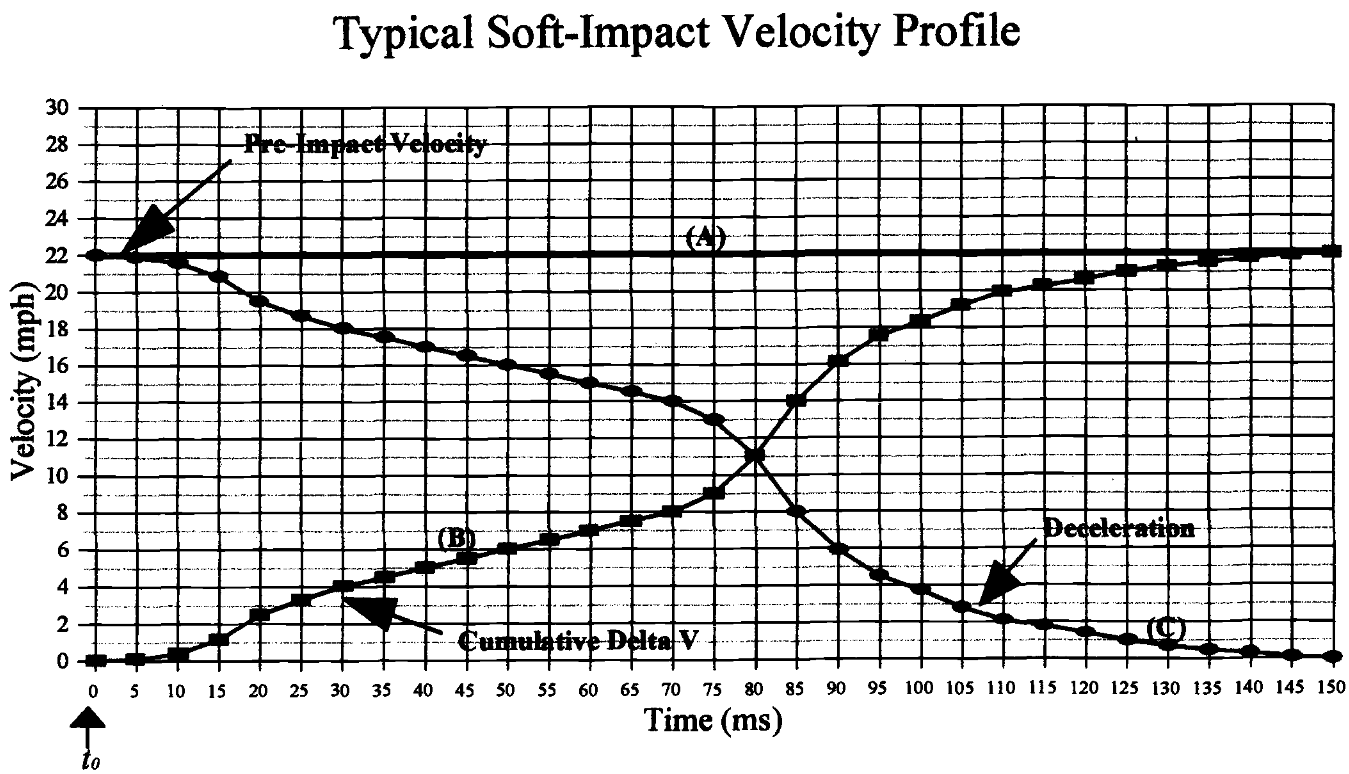


FIG. 5.7—Impact velocity shown decreasing versus time after impact, and cumulative Delta V (pre-impact velocity minus current velocity) shown increasing versus time.

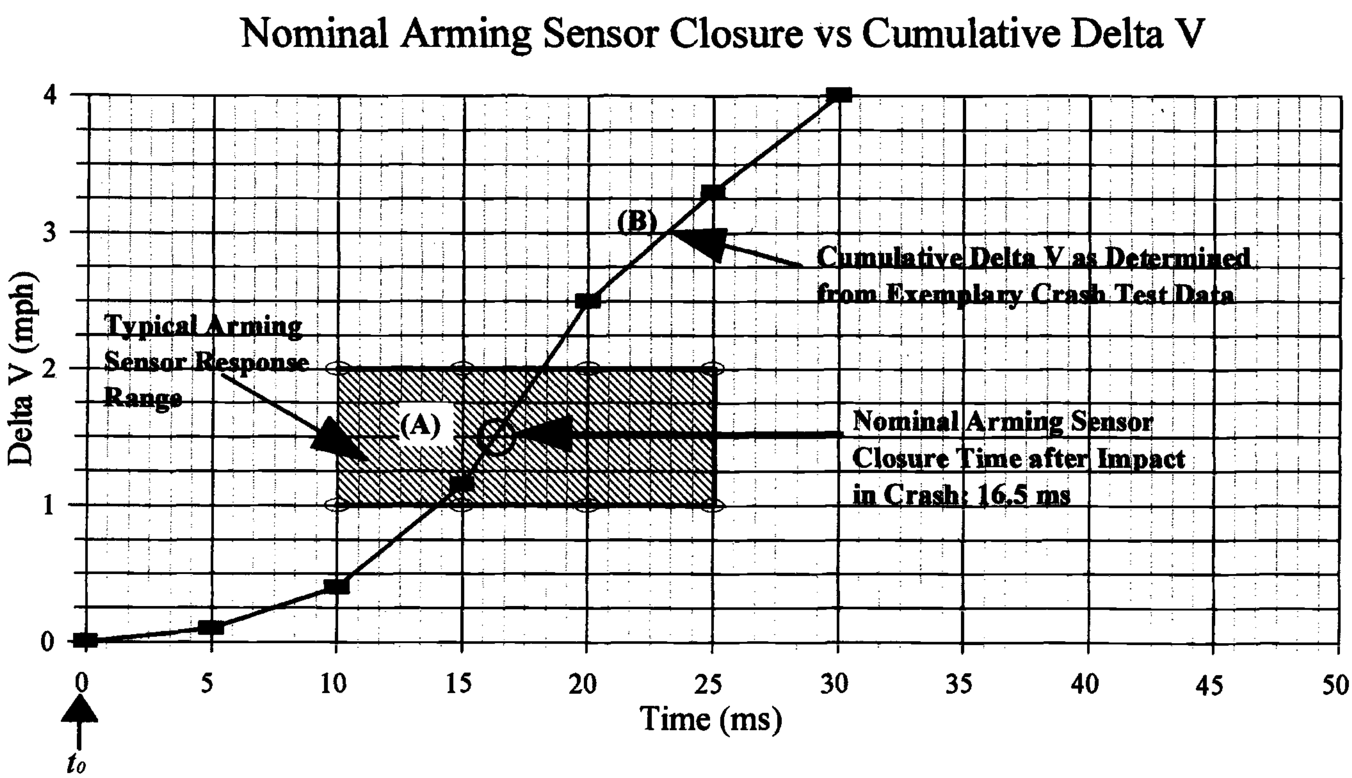


FIG. 5.8—Determining arming sensor closure timing using crash pulse and sensor characteristics.

complete our assignment, we now have to determine when the arming sensor would have closed in the crash (t_{arming}).

To do this, we will need to know the specification for arming sensor function (closure of the arming sensor-switch versus cumulative Delta V versus time). Arming sensors have a typical closure threshold response corresponding to a cumulative Delta V of 1 to 2 mph in the time range of 5 to 30 ms (after impact). We can then determine when the example cumulative Delta V of Fig. 5.7 would cause the arming sensor to close (t_{arming}).

Figure 5.8 allows us to determine a nominal value of $t_{arming\text{-}nom}$ by examining the very beginning of our example crash cumulative Delta V (B) overlayed on a typical closure threshold response range (A). Our example cumulative Delta V traverses the typical arming sensor response range between 14 ms (at 1 mph) and 18 ms (at 2 mph), and crosses the midpoint threshold (1.5 mph) at 16.5 ms.

We can now state the nominal total time to fire by summing $t_{arming\text{-}nom}$ plus the time from arming closure to sensor overlap as recorded by the SRS ECU.[9] This total time to fire after impact is

$$t_{fire\text{-}nom} = 16.5 \text{ ms} + 61 \text{ ms} = 77.5 \text{ ms}$$

and this is shown graphically in Fig. 5.9.

[9]The distributed sensor SRS ECU can only record those parameters that it can electrically recognize, such as switch closures. It cannot recognize the onset of acceleration because it has no acceleration-detecting sensor, other than the external sensor-switches.

We call this a first pass analysis because we have utilized a nominal sensor characteristic and a single example crash pulse. In actual practice, sensors have response tolerances that vary with age and temperature, and crash pulses normally have a tolerance range.

In the next subsection we shall perform a sensitivity analysis to examine how sensor tolerances and crash pulse variances affect our first pass timing analysis.

5.5.3 Sensitivity Analysis to Examine How Sensor Tolerances Can Affect First Pass Timing Calculation

For our first pass analysis, we derived a nominal arming sensor closure time by using a value at the center of its sensitivity range. However, we have to understand that a sensitivity range is given because of many variables that influence real world sensor response. These include temperature, age, manufacturing test acceptance limits, etc. In our example of Fig. 5.8, the least responsive sensor would respond by a cumulative Delta V of 2.0 mph (3.22 kph), and the most responsive sensor would respond by a cumulative Delta V of 1.0 mph (1.61 kph), and any value in between would be an acceptable sensor response.

Given this variance in acceptable sensor responses, we can see from Fig. 5.6 that the earliest t_{arming} would be at 14 ms (at 1 mph) and the latest t_{arming} would be at 18 ms (at 2 mph). Thus, we can now state the fire command time as being bounded in a range:

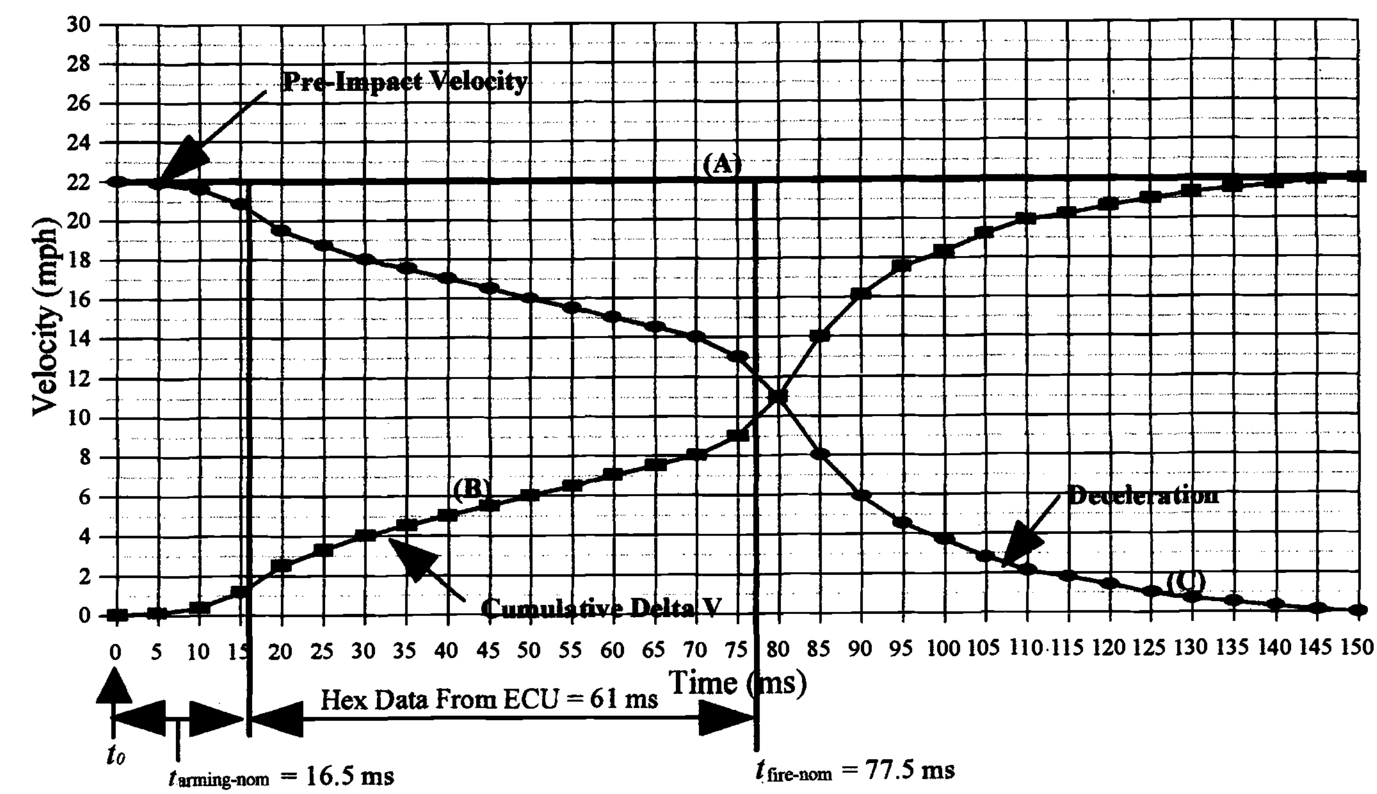


FIG. 5.9—First pass timing analysis using typical arming sensor characteristics and cumulative Delta V.

$$t_{\text{fire-max}} = 18.0 \text{ ms} + 61.0 \text{ ms} = 79.0 \text{ ms}$$

$$t_{\text{fire-min}} = 14.0 \text{ ms} + 61.0 \text{ ms} = 75.0 \text{ ms}$$

We can now state that, with respect to sensor responsiveness variables, our nominal time to fire, $t_{\text{fire}} = 77.5$ ms, can have a potential error of

$$\frac{\pm 1.5}{77.5} \text{ ms} = \pm 1.94\%$$

Similarly, we can also include calculations that account for variations in cumulative Delta V responses across different crash tests. A full study of the probability distribution of air bag and ETR deployment times (t_{fire}) between complex early versus late limits is beyond the scope of this book; however, the evaluation of the sensitivity of an investigator's calculation to such limits can help establish the credibility and reliability of the investigator's analysis.

Using ECU Electronic Data to Derive Case-Specific Analyses

6

6.1 CASE ANALYSIS OBJECTIVES AND INTRODUCTION

VEHICLE SAFETY AND RESTRAINT SYSTEMS design involves many compromises and tradeoffs to optimize the system performance required by federal safety standards. These standards apply to many different vehicles, each with unique roadability and crush characteristics. Thus, for each vehicle, safety and system-initiation sensors and safety system actuators must be calibrated, or modulated, to operate in a beneficial manner. Simply put, this means that these systems must not operate too early or too late in a scenario requiring their actuation, and this applies to SRS, ABS, and TCS features. The overall record is very good, and a tabulation of lives-saved versus injury-induced data has already been shown in Fig. 3.1.

The objective of all the analyses in this book is to see if, and how completely, we can synthesize the anatomy of a crash from the partial data in various post-crash sources. In this chapter, we are going to look at examples of post-crash-downloaded ECU saved data from multiple electronic sources and see how these data can be used to provide information about the crash event. We will do this by reviewing six case study examples of crash data analysis, each having a different system type and format. These case studies will utilize the conventions, glossary, acronyms, and system parameters discussed in previous chapters.

For each of those cases, we will walk through a step-by-step analysis and show how our results were derived. These exercises are undertaken to give the reader set methodologies that he or she can employ or adapt to other systems of specific interest. In some examples, we will show how to determine vehicle acceleration data versus occupant acceleration data, and, from that, determine an occupant-to-vehicle closing distance versus time-after-impact and occupant-to-air bag interactions in a crash event. In several examples, we will see how to determine seat occupancy, seat belt usage, and prior fault and repair history. Where it is available, we will also show how supporting data from ABS/TCS/PCM ECU freeze frames can be used to confirm our case analysis.

Lastly, we shall see examples of how to extend our analysis from mere data translations to a second, more sophisticated, level of our study of the anatomy of a crash, and how those results can provide quantitative data to investigators in associated sciences (medical, biomechanics, human factors, etc.).

6.2 THE ANATOMY OF A CRASH PULSE AND ASSOCIATED FREEZE FRAME DATA

In accordance with Newton's laws of motion as explained in Chapter 2, in general, at a steady state road speed, a vehicle can be considered to have an equilibrium of forces acting upon it. To simplify our crash analysis, we will assume for our examples that in the instant before impact, the bullet vehicle is coasting into its target impact object at a steady speed (its pre-impact velocity). Thus, the only force we need to consider in our analysis is the force exerted by the target impact object into the vehicle, in the PDOF direction, which generally contains Y axis and –X axis components. This force then creates a deceleration of the bullet vehicle, which acts against the pre-impact velocity to reduce that vehicle's velocity. That change in velocity is known as the bullet vehicle Delta V (ΔV). The time over which the ΔV occurs (t_{crash}) determines the acceleration (or deceleration, a) pulse experienced by the bullet vehicle.

During the period after contact, the vehicle is experiencing increasing crush and an expanding pattern of component damage. This can be visualized by referring to the post-impact time line in Fig. 6.1 and is summarized as follows:

1. The front of the vehicle starts to deform and crush.
2. Components in the crush zone start to be displaced from their original positions.
3. Wiring harnesses to the displacing components start stretching.
4. As displacement continues, wires stretch, connectors pop off, and components are crushed.
5. As connectors pop off and components are crushed, associated ECUs detect operating malfunctions and generate DTCs. These DTCs are event-triggered, and the triggering event is component damage caused by impact damage.
6. In the same actions that save the DTCs, selected freeze frames are saved.
7. Depending on impact severity, vehicle power may be lost.
8. Even if power is lost, EEPROM/flash memory retains the saved DTCs and associated freeze frame data.
9. After the crash event, EEPROM/flash memory can be interrogated using scanners to retrieve saved DTCs and associated freeze frame data.

In the six case examples to follow, we will be examining the information available in crash event freeze frame hexadecimal data. As illustrative examples of such information, Fig. 6.2 shows an example of current seat belt status as detected by a scanner, and Fig. 6.3 shows an example of seat belt status that existed at the time of the crash event (EEPROM data download months after the crash event).

6.3 OCCUPANT DYNAMICS WITH RESPECT TO A VEHICLE IMPACT AND AIR BAG DEPLOYMENTS

For an occupant in a frontal crash, especially during the early stages of a crash impact, one can assume that the un-

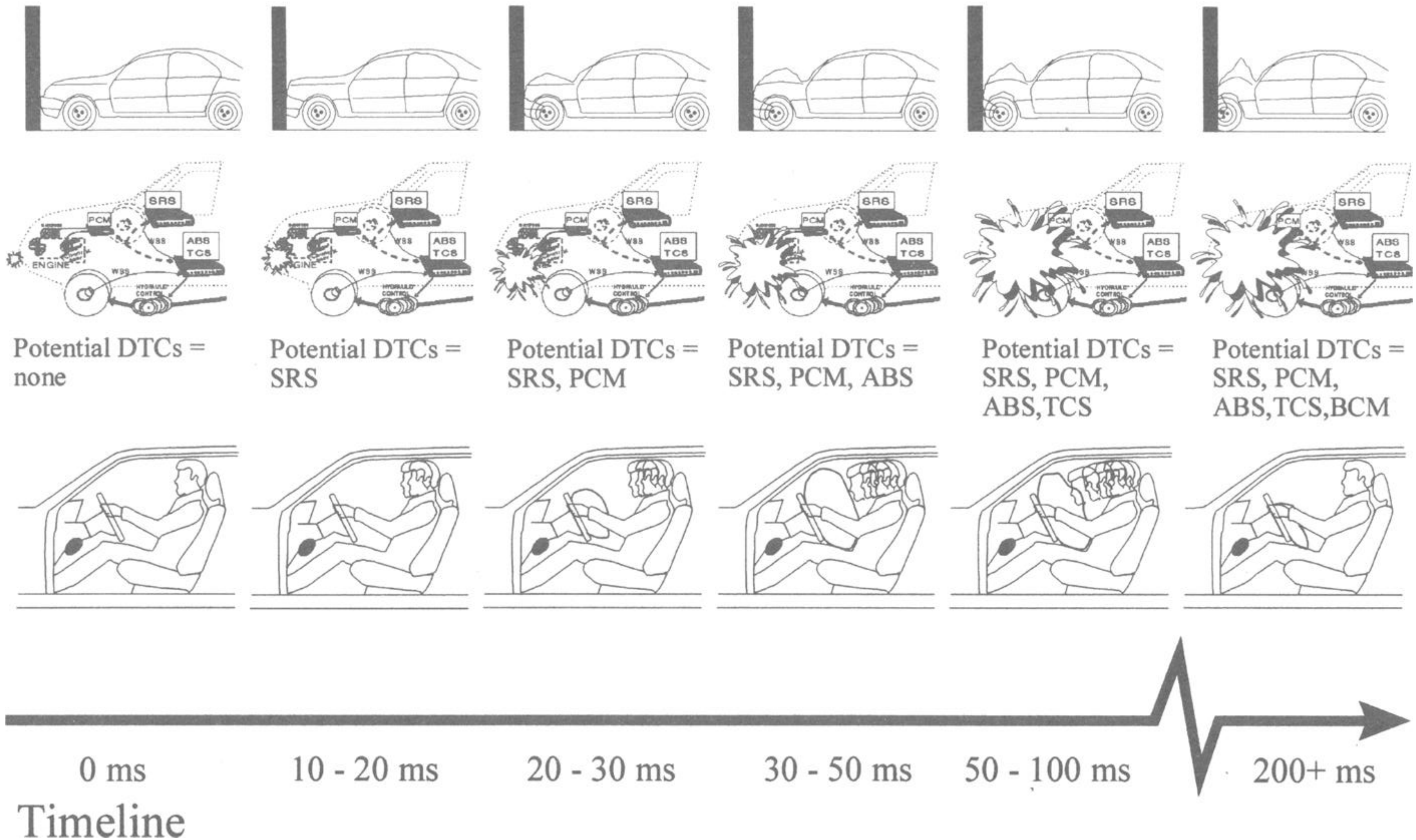


FIG. 6.1—Crash time line showing potential event-triggered DTCs and air bag deployment phases versus time after impact. Each DTC can cause a freeze frame to be saved in EEPROM/flash memory in its respective ECU.

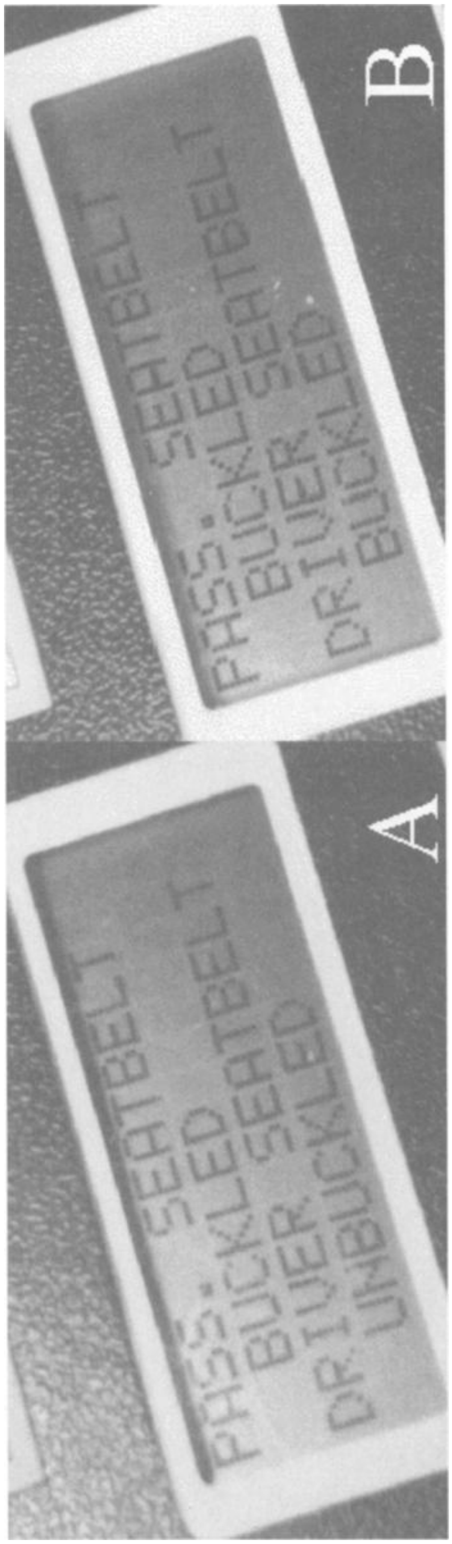


FIG. 6.2—Example showing detection of normal operation of seat belt status by a diagnostic scanner.

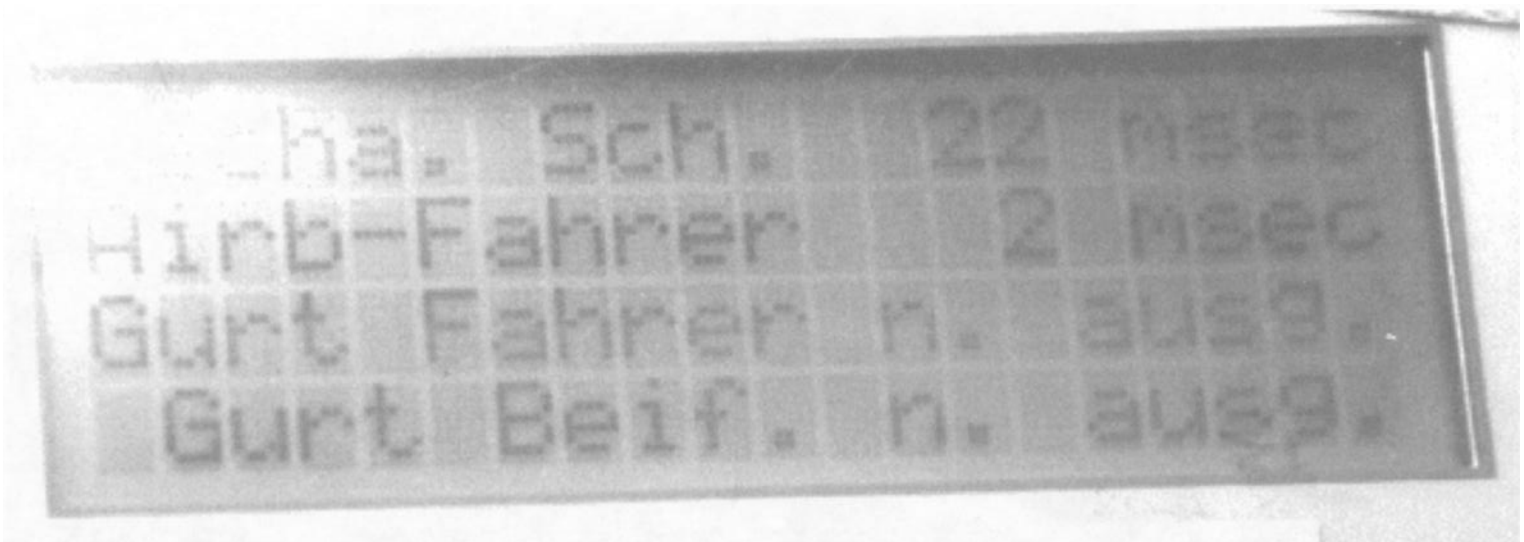


FIG. 6.3—Example showing how one system scanner interprets downloaded EEPROM data to present seat belt status that existed at the time of the crash event. (Data download months after the crash event.) Note that the German translation is interpreted as:

Mecha Sch = Arming Sensor, 22 ms
Airb-Fahrer = Driver Air Bag, 2 ms
Gurt Fahrer = Driver seat belt (not out of retractor)
Gurt Beif = Passenger seat belt (not out of retractor)
(not out of retractor = not used/unbuckled)

restrained occupant, or those parts of the body that are unrestrained (such as the head), remain at the pre-impact vehicle velocity, while the post-impact vehicle frame velocity diminishes in accordance with the deceleration sensed by the SRS accelerometers (switches or continuous analog devices). If we know, or can later determine, the seated position of the occupant with respect to the wheel, or the instrument panel surface, we can calculate the occupant-to-vehicle closing distance versus time (Breed and Castelli 1988; Huang et al. 1991; Spiess et al. 1997).

There are two ways of viewing this problem:

- The first approach is to calculate the post-impact distance traveled versus time, relative to the earth, for both the occupant and the vehicle. Since the vehicle is slowing,[1] but the unrestrained occupant is not, the occupant catches up with the vehicle after some period of time.[2] This is illustrated in Fig. 6.4.
- The second approach is to consider that both the occupant and the vehicle are stationary at pre-impact, and, after impact, the vehicle starts to move rearward, toward the stationary occupant until it hits the occupant as shown in Fig. 6.5.

Both approaches produce identical results and will be illustrated in the case evaluations.

6.4 HYPOTHETICAL CASE 1, ANALYSIS OF A CRASH WHERE SWITCH-SENSOR TIME INTERVALS ARE RECORDED

In this case analysis, the SRS uses inertia switches (sensors) to detect the crash deceleration condition. The ECU records the time interval between the initiating sensor closure (safing/arming) and the confirming sensor closure (crash/discriminating), which initiates the air bag deployment. Various other parameters recorded by such ECUs can include seat belt usage, ignition cycle count, system fault status, system electrical parameters, and air bag lamp status. Such ECUs can typically record data for one to eight crashes.

In the Case 1 example, the downloaded EEPROM data are listed as address-blocked hexadecimal values, as shown in Fig. 6.6. Figure 6.7 expands all data addresses into a line, listing the hexadecimal value, decimal equivalent, binary equivalents, and an interpretation of the equivalents with respect to specific information formats.

From the data translation, Fig. 6.7, we can see that this hypothetical ECU can record three crash events, and two of those events have data stored.

6.4.1 Evaluation of Case 1 Data in Address Sequence

The data byte at address \$0000, \$4B, tells us that the software is Version 4, Level B. This parameter was evaluated as a State Encoded value of the hex/binary data (per Chapter 2.6.2, SAE J2178-2:6).

The data byte at address \$0001, \$6B, tells us that the month and the year of the software release was November 1996. This parameter is evaluated as a State Encoded value of the hex/binary data (per Chapter 2.6.2, SAE J2178-2:6).

The data byte at address \$0002, \$1B, tells us that the day of the software release was the 27th. This parameter was evaluated as a straight Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4).

The data bytes at addresses \$0003 to \$0004, \$0D93, give us the value of the ignition cycle counter at the time of our interrogation (3475). From the data bytes at addresses \$000B to \$000C, \$0D92, and addresses \$0012 to \$0013, \$0D92, which document the ignition counter for Crashes 1 and 2 respectively, we see that both crashes happened in the same

[1] In accordance with the deceleration sensed by the SRS accelerometers.

[2] Of course, all air bag SRS systems have a design objective to deploy the air bag well before the occupant catches up with the vehicle wheel/dash.

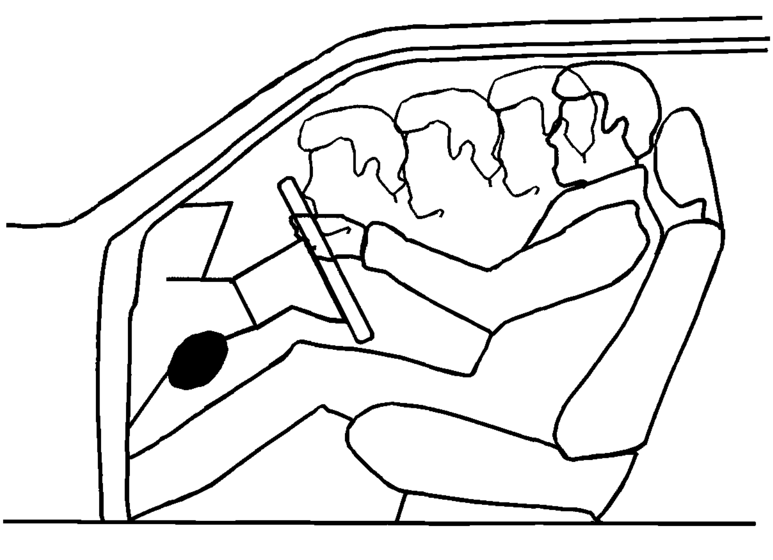


FIG. 6.4—Driver to vehicle distance is closing because the unrestrained driver catches up with the slowing vehicle after impact.

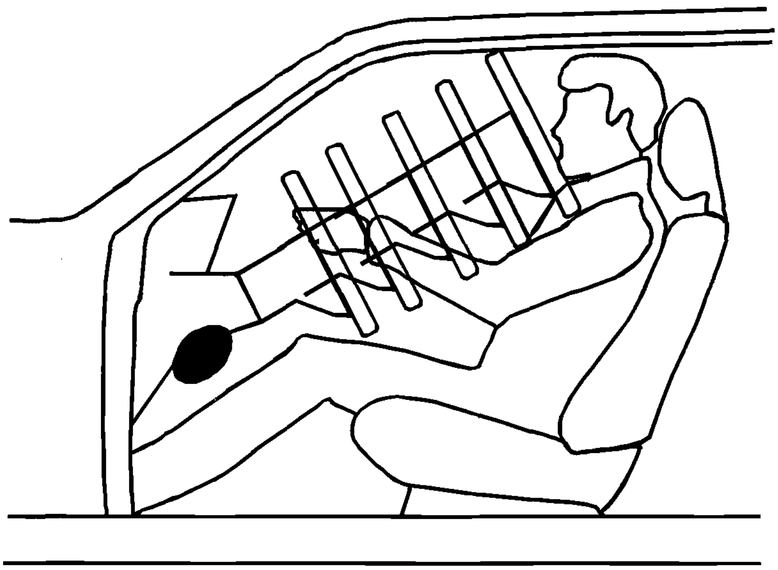


FIG. 6.5—Alternative viewpoint, vehicle to driver distance is closing because the vehicle accelerates toward the driver after impact.

```
HYPOTHETICAL EEPROM DATA LISTING (FORMATTED HEX)

HEX
WORD
ADDRS  ---------------HEX BYTE ADDRESS ---------------
xx00   00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F

0000   4B 6B 1B 0D 93 21 83 5D D1 00 00 0D 92 7F 5D 11
0010   01 81 0D 92 81 00 00 00 00 00 00 00 00 00 00 00
0020   00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0030   00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0040   00 00 00 00 00 00 00 00    ERROR CODES &
0050   00 00 00 00 00             EEPROM DATA
```

FIG. 6.6—Formatted hex listing for Hypothetical Case 1.

ignition cycle (3474), and that we are in the very next ignition cycle since the crash. Thus, there were no intervening key on cycles before the interrogation. These parameters were evaluated as straight Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4).

The data bytes at addresses $0005 to $0006, $2183, tell us that there are five faults (DTCs) in history, 14, 21, 40, 61, and 62. The data bytes at addresses $0009 to $000A, $0000, tell us that there were no faults in history or existing at the time of Crash 1. The data bytes at addresses $0010 to $0011, $0181, tell us that Faults 21, 40, and 62 were present at Crash 2. However, Crash 1 and Crash 2 occurred in the same ignition cycle (3474). Knowing that there were no faults existing before Crash 1, we now know that Crash 1 generated Faults 21, 40, and 62. We also know that additional Faults 14 and 61 were generated after Crash 2, since they are now stored in the global history faults, documented at addresses $0005 to $0006. These parameters are evaluated by observing the mask bit position versus the stated DTC map (i.e., a "1" indicates that a DTC in that physical bit position was true). This interpretation corresponds to a Bit Mapped without Mask Byte format per Chapter 2.6.2, SAE J2178-2:2.

The data byte at address $0007, $5D, shows us that in Crash 1 the driver (LF) was not wearing a seat belt, the passenger (RF) was wearing a seat belt, the RR passenger was wearing a seat belt, and that the arming (Arm), discriminating 1 (D1), and discriminating 3 (D3) sensors were closed. These parameters are evaluated by observing the mask bit position versus the stated condition map (i.e., a "1" indicates that the condition designated by that physical bit position was true). This interpretation corresponds to a Bit Mapped without Mask Byte format per Chapter 2.6.2, SAE J2178-2:2.

The data byte at address $0008, $D1, tells us that Crash 1 had a relatively long time until complete detection (78 ms from arming sensor closure to simultaneous discriminating sensor closure, or overlap), whereas address byte $000F tells us that Crash 2 was detected quickly (12 ms from arming

DATA BYTE ADDR EXAMPLE	DATA - BYTE VALUE - HX	DEC	BINARY	INTERPRETED MEANING & ENCODING	TRANSLATION FOR THIS HYPOTHETICAL
0000:	4B	75	01001011	SOFTW IDENT version, level	Version 4, Level B
0001:	6B	107	01101011	SOFTW DATE HI yr, month	{199}6, November
0002:	1B	27	00011011	SOFTW DATE LO day	27th day
0003:	0D	13	00001101	TOTAL IGN CYCLE COUNTR, HI BYTE, 256 per count	3328
0004:	93	147	10010011	TOTAL IGN CYCLE COUNTR, LO BYTE, units count, 0-255	+147 =-> 3475, total ign cycles
0005:	21	33	00100001	HISTORY FAULT FLAGS: 12 13 14 15 16 18 20 21	fault 14, 21 in history
0006:	83	131	10000011	HISTORY FAULT FLAGS: 40 43 45 51 52 53 61 62	fault 40, 61, 62 in history
0007:	5D	93	01011101	CR1 DvrSB,PasSB Snsrs Closed: LF,RF,LR,RR,A,D1,D2,D3	Dvr=UnB, Pas=Buckled;A,D1,D3 Closed
0008:	D1	209	11010001	CR1 TIME FROM A to 1^{ST} DISC SNSR, DISC ID nnnnnD1D2D3	3ms/count, 26x3=78ms, D3=1^{st} Disc Snsrclsd
0009:	00	0	00000000	CR1 HIST FAULT FLAGS: 12 13 14 15 16 18 20 21	No fault in history at crash event
000A:	00	0	00000000	CR1 HIST FAULT FLAGS: 40 43 45 51 52 53 61 62	No fault in history at crash event
000B:	0D	13	00001101	CR1 IGN CYCLE COUNTR, HI BYTE 256/count	3328
000C:	92	146	10010010	CR1 IGN CYCLE COUNTR, LO BYTE 0-255	+146 =-> 3474, ign cycle @ crash event
000D:	7F	127	01111111	CR1 AirBag Lamp, b7=on/off, 6-0=IgCyCnt 127max	Lamp OFF, 127 IgCycles
000E:	5D	93	01011101	CR2 DvrSB,PasB Snsrs Cosed: LF,RF,LR,RR,A,D1,D2,D3	Dvr=UnB, Pas=Buckled;A,D1,D3 Closed
000F:	11	17	00010001	CR2 TIME FROM A to 1^{ST} DISC SNSR, DISC ID nnnnnD1D2D3	3ms/count, 4x3=12ms, D3= 1^{st} cr Snsr clsd
0010:	01	1	00000001	CR2 HIST FAULT FLAGS: 12 13 14 15 16 18 20 21	fault 21 in history at crash event
0011:	81	129	10000001	CR2 HIST FAULT FLAGS: 40 43 45 51 52 53 61 62	faults 40, 62 in history at crash event
0012:	0D	13	00001101	CR2 IGN CYCLE COUNTR, HI BYTE 256/count	3328
0013:	92	146	10010010	CR2 IGN CYCLE COUNTR, LO BYTE 0-255	+146 =-> 3474, ign cycle @ crash event
0014:	81	129	10000001	CR2 Air Bag Lamp, b7=on/off, 6-0=IgCyCnt 127max	Lamp ON, 1 IgCycle
0015:	00	0	00000000	CR3 DvrSB,PasSB Snsrs Closed: LF,RF,LR,RR,A,D1,D2,D3	No crash 3 data
0016:	00	0	00000000	CR3 TIME FROM A to 1^{ST} DISC SNSR, DISC ID nnnnnD1D2D3	No crash 3 data
0017:	00	0	00000000	CR3 HIST FAULT FLAGS: 12 13 14 15 16 18 20 21	No crash 3 data
0018:	00	0	00000000	CR3 HIST FAULT FLAGS: 40 43 45 51 52 53 61 62	No crash 3 data
0019:	00	0	00000000	CR3 IGN CYCLE COUNTR, HI BYTE 256/count	No crash 3 data
001A:	00	0	00000000	CR3 IGN CYCLE COUNTR, LO BYTE 0-255	No crash 3 data
001B:	00	0	00000000	CR3 Air Bag Lamp, b7=on/off, 6-0=IgCyCnt 127max	No crash 3 data

FIG. 6.7—Case 1 expanded data showing one line per address, listing the hexadecimal value, decimal equivalent, binary equivalents, and interpretation of the equivalents with respect to specific formats.

sensor closure to simultaneous discriminating sensor closure, or overlap).[3] These parameters were evaluated as unsigned numerics from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4), with the scale factor = 3 ms/count). The data at addresses $0009 through $000C have been covered above.

The data byte at address $000D, $7F, tells us that the SRS MIL (air bag lamp) was off for at least 127 cycles before Crash 1. This is a complex data byte where Bit 7 indicates the state of the MIL ("0" = off) and Bits 6 to 0 are an unsigned numeric indicating the ignition cycles at the state defined in Bit 7 (127). The data byte at address $0014, $81, tells us that the SRS MIL came on between Crash 1 and Crash 2, because Bit 7 has changed to a "1" and the cycle count is now 1. So, these bytes are combined-format bytes. These parameters were evaluated by observing a combination of one mask bit (Bit 7, the leftmost bit), and then evaluating the decimal equivalent of the remaining six bits of hex/binary data (Bits 6 to 0).

6.4.2 Discussion of Case 1 Data

These evaluations allow us to us to look at the accident fact set and reconstruction for confirmation of a relatively soft first impact, such as an oblique or offset sheet metal deformation, followed by a relatively stiff second impact, such as a brick wall. One aspect of an investigation in such a case would be whether the driver injuries (caused by steering wheel impact) came about because of a late deployment in the soft first impact, or because the driver was unprotected in the second crash (a stiff impact) after the air bag had deployed, as expected, in the first crash.

In this case, the EEPROM freeze frame data, complemented with accident reconstruction data, allow us to compile an analysis of crash timing and dynamics. Figure 6.8 shows the two crashes with a reconstructed Delta V of 28 to 32 mph (30 mph, 48 kph, average) in Crash 1, and a reconstructed Delta V of 17 to 20 mph (18.5 mph, 29.8 kph, average) in Crash 2 (where the vehicle was stopped by a hard barrier impact. Thus, if the reconstruction was accurate, the vehicle initial velocity was 45 to 52 mph (48.5 mph, 78.1 kph, average).

Additionally, we have the ability to probe the ABS system for freeze frame data. As shown in Fig. 6.9 an example of freeze frame data associated with a DTC 25, LF WSS[4] dropout is seen to be 50 mph. This example freeze frame data can further confirm that the event occurred on the last ignition cycle (the crash cycle), that it happened at the reconstructed point of the Crash 1 impact (LF), and the brake was not applied. Thus, we have established a set of facts that are consistent between the accident reconstruction and the computer data interpretation.

We can now consider our verified 30 mph cumulative Delta V in Crash 1, and attempt to summarize occupant-to-

[3] In barrier crashes, the time between arming closure and first discriminating sensor closure is typically 10 to 20 ms, and this is the case for Crash 2. However, in offset, pole, oblique, and underride type impacts, these times can be 30 to 100 ms, or more.

[4] WSS (wheel speed sensor), the sensor used to detect that individual wheel speed in ABS.

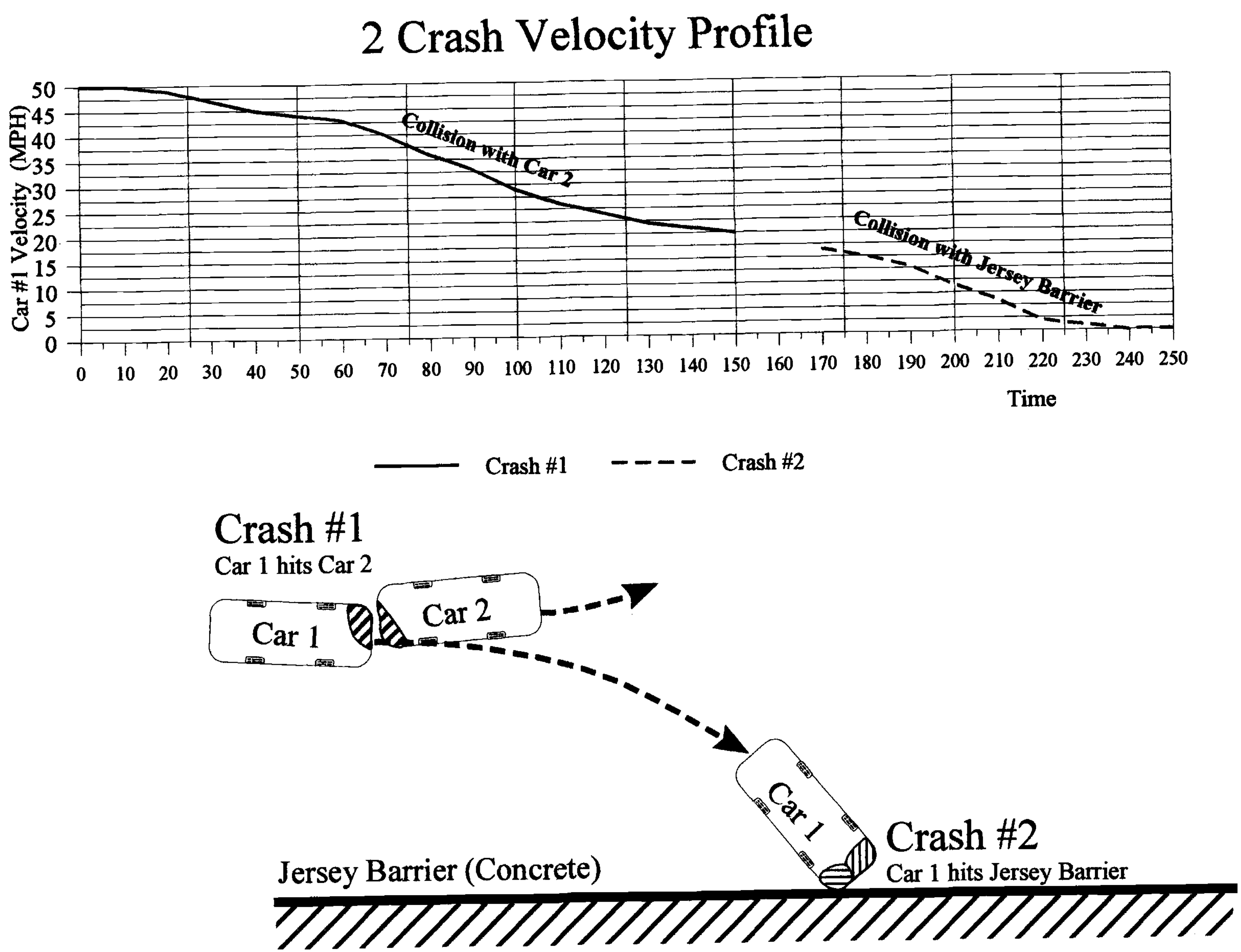


FIG. 6.8—Representative reconstruction analysis corresponding to Case 1 EEPROM data.

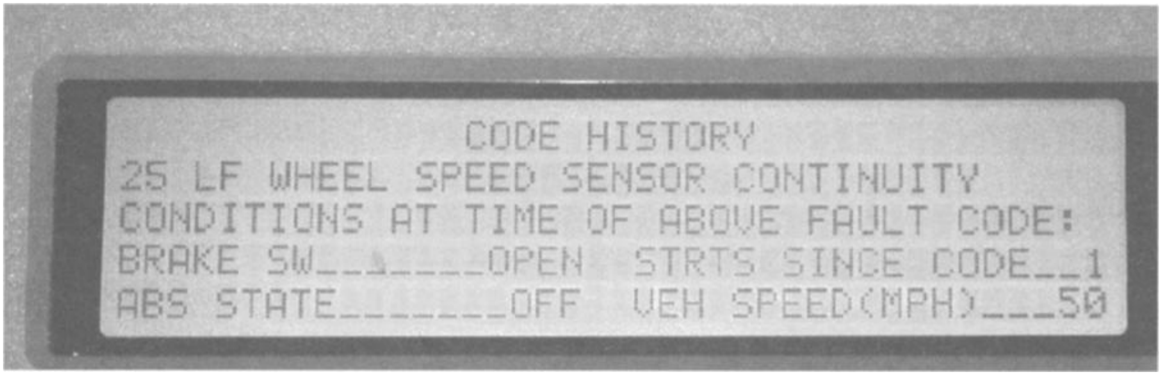


FIG. 6.9—ABS DTC 25 (left front wheel speed sensor) freeze frame record, showing ABS = off, brake not applied and a wheel speed of 50 mph at the time of the DTC, which occurred in the immediately previous ignition cycle.

vehicle dynamics with respect to the crash timing. This analysis is summarized in Fig. 6.10.[5]

Starting with an (unrestrained) operator to vehicle separation of 13 in., we can plot the forward movement of the vehicle versus the forward movement of the operator during the period of Crash 1 deceleration versus the known deployment timing of the air bag system. Figure 6.10 shows that the driver would have hit the steering wheel at 86 ms, before the air bag was deployed at 93 ms, and broke out of its cover at 98 ms.

Referring to Figs 6.1 and 6.10, we can review our Crash 1 analysis in the following step-by-step fashion:

1. We are assuming a standard symmetric haversine deceleration waveform model, and a Crash 1 cumulative Delta V of 30 mph (48 kph).
2. At T_0, the operator is seated 13 in. (32.5 cm) from the steering wheel.
3. At T_0, both the operator and the vehicle are moving at the full Crash 1 Delta V of 30 mph (48 kph).
4. At $T_0 + \varepsilon$,[6] the operator and the vehicle are still moving at 30 mph (48 kph). The e distance moved can be directly integrated as $V \times \Delta t$. This appears as a straight line.
5. As the vehicle impact proceeds and time progresses, the unrestrained operator travel distance still proceeds in a straight line product as the $\Sigma V \times \Delta t$.
6. However, as the vehicle impact proceeds, it decelerates as a response to crash force input, producing a haversine deceleration (i.e., negative acceleration).
7. As the vehicle velocity slows further, its travel distance further decreases (i.e., falls away from a nonimpact straight line 13 in. ahead of the operator). The magnitude of this distance decrease is the second integral of the deceleration (acceleration to stop the vehicle). The reader is referred to the discussion of Newton's laws in Chapter 2 for a foundation of the physical relationships implicit in these calculations.
8. The diminishing vehicle travel distance versus the linear travel distance of the unrestrained driver (with respect to earth coordinates) produces a closing of the initial separation of the driver from the steering wheel.[7]
9. At some point, there will be an intersection of the driver and the steering wheel. For the parameters of this accident, this occurs at approximately 86 ms after impact.
10. We assume that it took approximately 15 ms after impact for the arming sensor to close (reflecting a >1.0 to 1.5 mph cumulative Delta V at that point),[8] and we know from the SRS ECU crash record that there was a delay of 78 ms between the arming sensor closure and the discriminating sensor closure. Recall that, for this system, simultaneous closure of both sensors (or closure overlap) is required to fire the air bag. Thus, the air bag fire signal would first occur at 93 ms (15 ms + 78 ms).
11. If the driver's chest or head intersects the steering wheel at 86 ms, and the air bag fires at 93 ms, the driver will suffer a chest and/or head impact with the steering wheel before the air bag fires. Depending on driver rebound, he/she will then be subject to close-position injury from the deploying air bag (membrane loading) as it breaks out of its cover at approximately 98 ms (93 ms + 5 ms to breakout of cover).

Thus, we have established an analysis that confirms how the occupant was likely injured by the deploying air bag in Crash 1. The primary reason for this was the delayed discriminating sensor response because of relatively soft and offset impact. Potential injuries from the second crash would not be mitigated by any air bag protection because it was deployed prior to the second impact; however, they become supplementary to the principal injury mechanism. In such cases, one should look for occupant-to-vehicle impact artifacts and corresponding driver injuries. Deployment delays such as those illustrated here can be caused by placement of sensors (relative to impact location), low speed impacts, pole, offset, or underride impacts.

[5] The analysis methods used to create Fig. 6.9 have been verified against actual crash tests and have been found to be within ±5% variance of actual data for comparable vehicles. Considering crash parameter variables, crash data repeatability within ±5% of a mean is considered very good tracking, and tracking within ±10% of a mean is typical (Day 1989; McHenry Software).

[6] Epsilon, ε, is a universal symbol used to denote a very small movement from, or perturbation of, the foundation parameter or position.

[7] This is also treated in Breed and Huang.

[8] See supporting discussion in Chapter 5.4.2 and Fig. 5.7.

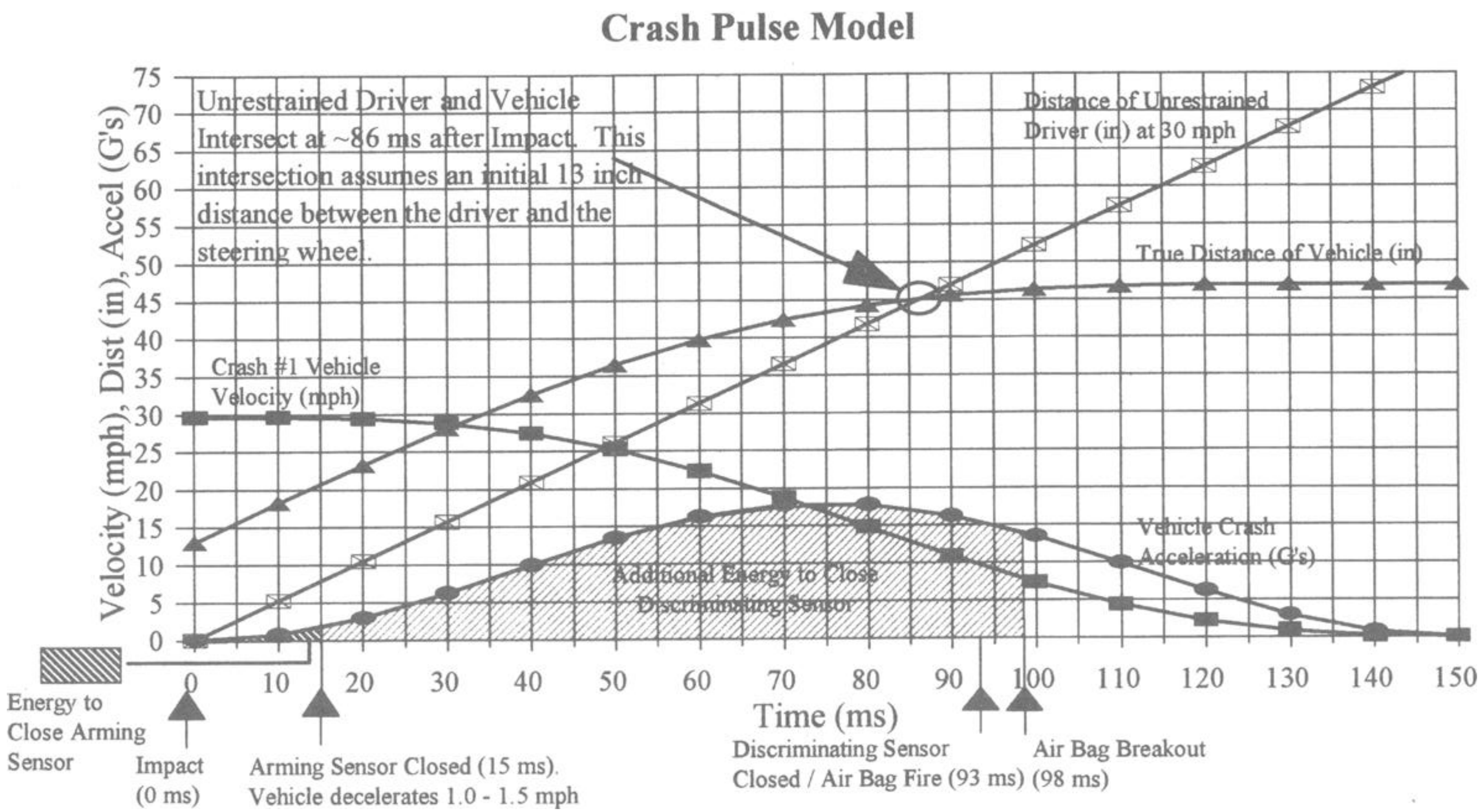


FIG. 6.10—Analysis for Case 1, Crash 1. The analysis shows a timing window wherein the driver would have hit the steering wheel before the air bag deployed in Crash 1. In such cases, one should look for a bent steering wheel rim, collapsed steering column, and corresponding driver injuries.

6.5 HYPOTHETICAL CASE 2, ANALYSIS OF A CRASH WHERE PEAK ACCELERATION AND BASE DURATION ARE RECORDED

In this hypothetical case analysis, the SRS uses an accelerometer internal to the ECU to detect the crash deceleration condition. The ECU records peak acceleration and base time duration of the crash pulse to EEPROM after it has made the decision to fire the air bag(s). Normally, a safing/arming sensor is also used to confirm proper conditions for air bag deployment. Various other parameters recorded by such ECUs can include seat belt usage, ignition cycle count, system fault status, system electrical parameters, and air bag lamp status. Such ECUs can typically record data for one to four crashes.

In the example shown below, we have taken the hypothetical EEPROM data record of Fig. 6.11 and interpreted it in Fig. 6.12.

6.5.1 Evaluation of Case 2 Data In Address Sequence

The data byte at address $0000, $4F, tells us that the software is Version 4, Level F. These parameters are evaluated as a State Encoded value of the hex/binary data (per Chapter 2.6.2, SAE J2178–2:6).

The data byte at address $0001, $79, tells us that the month and the year of the software release was July 1997. These parameters are evaluated as a State Encoded value of the hex/binary data (per Chapter 2.6.2, SAE J2178-2:6).

The data byte at address $0002, $10, tells us that the day of the software release was the 16th. This parameter was evaluated a straight Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4).

The data bytes at addresses $0003 to $0004, $0D04, give us the value of the ignition cycle counter at the time of our interrogation (3332). From the data bytes at addresses $000D to $000E, $0D01, which document the ignition counter for Crash 1, we see that the crash happened at Cycle 3329. We now know that there have been two ignition cycles (3330 and 3331, $0D02 and $0D03) in between the crash cycle and the current cycle. These parameters were evaluated as straight Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4).

The data bytes at addresses $0005 to $0006, $2003, tell us that there are three faults (DTCs) in history, 15, 71, and 72. Similarly, the data bytes at addresses $000B to $000C, $0000, tell us that there were no faults in history or existing at the time of Crash 1. These parameters are evaluated by observing the mask bit position versus the stated DTC map (i.e., a "1" indicates that a DTC in that physical-map position was true). This interpretation corresponds to a Bit Mapped without Mask format per Chapter 2.6.2, SAE J2178-2:2.

The data byte at address $0007, $29 = 41, shows us that a deployment was commanded 20.5 ms after the algorithm was enabled (i.e., after the acceleration value crossed a threshold). This parameter was evaluated as an Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4), with the scale factor = 0.5 ms/count).

The data byte at address $0008, $7A = 122 shows us that the time from algorithm enable to peak *G* value was 61.0 ms. This parameter was evaluated as an Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2: 4), with the scale factor = 0.5 ms/count.

The data byte at address $0009, $87 = 135 shows us that the total time that the acceleration value was over the minimum threshold (the base time of the crash pulse) was 135 ms. This parameter was evaluated as an Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2: 4), with the scale factor = 1.0 ms/count.

The data byte at address $000A, $49 = 73, shows us that the peak acceleration, in *G*s, was 14.6 *G*. This parameter was evaluated as an Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4), with the scale factor = 0.2 *G*/count.

The data at addresses $000B through $ 000E has been covered above.

The data byte at address $000F, $9D = 157 shows us that in Crash 1, the MIL was on for 29 cycles before the crash. This parameter was evaluated by observing a combination of one mask bit (Bit 7), and then evaluating the decimal equivalent of the remaining six bits of hex/binary data.

The data byte at address $0010, $2E = 46 shows us that in Crash 1 the driver (LF) was wearing a seat belt, and the passenger (RF) was a child and not wearing a seat belt. These parameters are evaluated by observing the mask bit position versus the stated condition map (i.e., a "1" indicates that the condition designated by that physical bit position

```
HYPOTHETICAL EEPROM DATA LISTING (FORMATTED HEX)

HEX
WORD
ADDRS --------------HEX BYTE ADDRESS --------------
xx00  00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F

0000  4F 79 10 0D 04 20 03 29 7A 87 49 00 00 0D 01 9D
0010  2E 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0020  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0030  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0040  00 00 00 00 00 00 00 00
0050  00 00 00 00 00                ERROR CODES &
                                    EEPROM DATA
```

FIG. 6.11—Formatted hex listing for Hypothetical Case 2.

```
DATA       DATA
BYTE    - BYTE VALUE -
ADDR    HX DEC BINARY    TRANSLATED MEANING & ENCODING                        TRANSLATION FOR THIS HYPOTHETICAL EXAMPLE
----    -- --- --------  ---------------------------------------------------  ----------------------------------------

0000:   4F  79 01001111  SOFTW IDENT version, level                           Version 4, Level F
0001:   79 121 01111001  SOFTW DATE HI  yr, month                             {199}7, Sept
0002:   10  16 00010000  SOFTW DATE LO  day                                   16th day
0003:   0D  13 00001101  TOTAL IGN CYCLE COUNTR, HI BYTE, 256 per count       3328
0004:   04  04 00000100  TOTAL IGN CYCLE COUNTR, LO BYTE, units count, 0-255  +004  ==> 3332, total ign cycles, incl
0005:   20  32 00100000  HISTORY FAULT FLAGS: 13 14 15 16 18 20 21 25         fault 15 in history
0006:   03   3 00000011  HISTORY FAULT FLAGS: 30 33 35 41 42 43 71 72         fault 71,72 in history
0007:   29  41 00101001  CR1 ALG OV ENAB THRESH - DEPLY COMMD TIME 0.5ms/COUNT 20.5 ms
0008:   7A 122 01111010  CR1 ALG ENAB-PEAK G,                 TIME 0.5ms/COUNT 61.0 ms
0009:   87 135 10000111  CR1 ALG OVER ENAB THRESHOLD          TIME 1.0ms/COUNT 135  ms
000A:   49  73 01001001  CR1 PEAK G                         Accel 0.2G/ count  14.6 G
000B:   00   0 00000000  CR1 HIST FAULT FLAGS: 13 14 15 16 18 20 21 25         No fault in history
000C:   00   0 00000000  CR1 HIST FAULT FLAGS: 30 33 35 41 42 43 71 72         No fault in history
000D:   0D  13 00001101  CR1 IGN CYCLE COUNTR, HI BYTE  256/count              3328
000E:   01 001 00000001  CR1 IGN CYCLE COUNTR, LO BYTE  0-255                  +001 ==> 3329, ign cycle @ crash event
000F:   9D 157 10011101  CR1 AirBag Lamp, b7=on/off, 6-0=IgCyCnt 127max        Lamp ON, 29 IgCycles
0010:   2E 046 00101110  CR1 x, x, DvrSB,PasSB, LFOcc, RFOcc, LFAd/Ch, RFAd/Ch Adult Dvr=Buckled, Child Pas=Unbuckled
0011:   00 000 00000000  CR2 ALG OV ENAB THRESH - DEPLY COMMD TIME 0.5ms/COUNT No Second Crash
0012:   00 000 00000000  CR2 ALG ENAB-PEAK G,                 TIME 0.5ms/COUNT
0013:   00 000 00000000  CR2 ALG OVER ENAB THRESHOLD          TIME 1.0ms/COUNT
0014:   00 000 00000000  CR2 PEAK G                         Accel 0.2G/ count
0015:   00 000 00000000  CR2 HIST FAULT FLAGS: 13 14 15 16 18 20 21 25
0016:   00 000 00000000  CR2 HIST FAULT FLAGS: 30 33 35 41 42 43 71 72
0017:   00 000 00000000  CR2 IGN CYCLE COUNTR, HI BYTE  256/count
0018:   00 000 00000000  CR2 IGN CYCLE COUNTR; LO BYTE  0-255
0019:   00 000 00000000  CR2 Air Bag Lamp, b7=on/off, 6-0=IgCyCnt 127max
001A:   00 000 00000000  CR2 xx, DvrSB,PasSB;Pos Occ LF,RF Adult/Chld LF,RF
```

FIG. 6.12—Case 2 interpreted data showing one line per address, listing the hexadecimal value, decimal equivalent, binary equivalents, and interpretation of the equivalents with respect to specific formats.

was true). This interpretation corresponds to a Bit Mapped without Mask Byte format per Chapter 2.6.2, SAE J2178-2: 2.

The remaining data bytes are all 0, so we only have Crash 1 to consider.

6.5.2 Discussion of Case 2 Data

In this case, we see that the air bag ECU can save only two crash events and has data in only the first event history addresses. The data show that the crash pulse consisted of a peak *G* value of 14.6 *G*s over a 135 ms period, and that the crash was approximately symmetric (peak *G* point at 61/135 ms). Further, the system's specifications indicate the haversine model has been used in the design of this system.[9]

From this information, we can proceed as follows to determine the ΔV for the crash event using our haversine model.

$$\Delta V_{\text{event}} = 1/2[a_{\text{peak}}][t_{\text{pulse}}]$$

$$= 0.5 * 470.12\ \text{ft/s}^2 * 0.135\ \text{s} = 31.73\ \text{ft/s}$$

$$= 21.64\ \text{mph}\ (34.82\ \text{kph})$$

As additional evidence in crashes, we can see corresponding DTCs, such as the example emissions DTC *P0112, IAT*[10] *SENSOR LOW VOLTAGE,* shown in Fig. 6.13. Its saved freeze frame data indicates that the vehicle speed was 21 mph. Since this DTC is a Type "A" code, which turns on the MIL and saves its freeze frame on the first occurrence, and the sensor related to it is in the front of the engine, it can be a good corroboration of our crash data Delta V analysis.

```
1996 DOMESTIC TRUCK         A/C
5.7L V8 CSFI                A/T
 **  CODES & DATA.  OK TO DRIVE.  **
P0112 IAT SENSOR LOW VOLTAGE
    FREEZE FRAME  /  FAILURE RECORD DATA
ENGINE LOAD(%)___36  COOLANT(EC)_______92
ST TRIM_________129  ST TRIM-1(%)_____0.8
LT TRIM_________128  LT TRIM-1(%)_____0.0
ST TRIM-2(%)___-1.6  LT TRIM-2(%)_____0.0
MAP(kPa)_________94  ENGINE RPM_____1879
VEH SPEED(MPH)___21  MAF(gm/Sec)___73.65
```

FIG. 6.13—DTC and freeze frame data (from a Snap-On MT2500) representative of a frontal crash induced malfunction in Case 2. Note that DTC P0112 is a type "A" code, which turns on the MIL and saves its freeze frame on the first occurrence.

6.6 HYPOTHETICAL CASE 3, ANALYSIS OF A CRASH WHERE TIME PERIOD ACCELERATIONS ARE RECORDED

In this hypothetical case analysis, the SRS uses an accelerometer internal to the ECU to detect the crash deceleration condition. The ECU records acceleration values every 5 ms for the duration of the crash pulse to RAM during its crash data processing (up to 135 ms), and then records those values to EEPROM, after the air bag(s) have been deployed. Normally, a safing/arming sensor is also used to confirm proper conditions for air bag deployment. Various other parameters recorded by such ECUs can include seat belt usage, ignition cycle count, system fault status, system electrical

[9]Note that the time of air bag fire is normally well before the full Delta V occurs. Such systems are typically calibrated to fire when the cumulative Delta V is 9 to 12 mph (14.5 to 19.3 kph).

[10]IAT = intake air temperature. The sensor for this parameter is usually located on the air intake tube, near the front of the vehicle.

parameters and air bag lamp status. Such ECUs can typically record data for one to two crashes.

In the example shown below, we have taken the hypothetical EEPROM data record of Fig. 6.14 and interpreted it in Fig. 6.15.

6.6.1 Evaluation of Case 3 Data In Address Sequence

The data byte at address $0000, $2B, tells us that the software is Version 2, Level B. This parameter were evaluated as a State Encoded value of the hex/binary data (per Chapter 2.6.2, SAE J2178-2:6).

The data byte at address $0001, $78, tells us that the month and the year of the software release was August 1997. These parameters were evaluated as a State Encoded value of the hex/binary data (per Chapter 2.6.2, SAE J2178-2:6).

The data byte at address $0002, $1A, tells us that the day of the software release was the 26th. This parameter was evaluated as a straight Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4).

The data bytes at addresses $0003 to $0004, $1C84, give us the value of the ignition cycle counter at the time of our interrogation (7300). From the data bytes at addresses $000D to $000E, $1C83, which document the ignition counter for the crash, we see that the crash happened at Cycle 7299. We now know that there have been no ignition cycles between the crash cycle and the current cycle. These parameters were evaluated as straight Unsigned Numerics from the hex/binary data (per Chapter 2.6.2, SAE J2178-2: 4).

The data bytes at addresses $0005 to $0006, $2003, tell us that there are three faults (DTCs) in history, 15, 71, and 72. Similarly, the data bytes at addresses $000B to $000C, $0000, tell us that there were no faults in history or existing at the time of the crash. These parameters are evaluated by observing the mask bit position versus the stated DTC map (i.e., a "1" indicates that a DTC in that physical bit position was true). This interpretation corresponds to a Bit Mapped without Mask Byte format per Chapter 2.6.2, SAE J2178-2:2.

The data byte at address $0007, $29 = 41, shows us that a deployment was commanded 20.5 ms after the algorithm was enabled (i.e., after the acceleration value crossed a threshold). This parameter was evaluated as an Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4), with the scale factor = 0.5 ms/count).

The data byte at address $0008, $7A = 122, shows us that the time from algorithm enable to peak *G* value was 61.0 ms. This parameter was evaluated as an Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2: 4), with the scale factor = 0.5 ms/count.

The data byte at address $0009, $87 = 135, shows us that the total time that the acceleration value exceeded the minimum threshold (the base time of the crash pulse) was 135 ms. This parameter was evaluated as an Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2: 4), with the scale factor = 1.0 ms/count.

The data byte at address $000A, $49 = 73, shows us that the peak acceleration, in *G*s, was 14.6 *G*. This parameter was evaluated as an Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4), with the scale factor = 0.2 *G*/count.

The data at addresses $000B through $000E has been covered above.

The data bytes in addresses $000F through $0029 represent 27 periods of (averaged) period acceleration data. They are plotted in Fig. 6.16. These parameters were evaluated as Unsigned Numeric values from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4), with the scale factor = 0.1 *G*/count.

The data byte at address $002A, $0A = 10, shows us that in the crash event, there was an adult driver (LF) who was not wearing a seat belt, and there was no RF passenger. These parameters are evaluated by observing the mask bit position versus the stated condition map (i.e., a "1" indicates that the condition designated by that physical bit position was true). This interpretation corresponds to a Bit Mapped without Mask Byte format per Chapter 2.6.2, SAE J2178-2:2.

6.6.2 Discussion of Case 3 Data

Knowing the time period accelerations stored in the ECU, EEPROM allows us to determine the approximate Delta V at the ECU location by performing a numeric integration of the sector average acceleration values, much as we did in Section 2.

```
HYPOTHETICAL EEPROM DATA LISTING (FORMATTED HEX)

HEX
WORD
ADDRS --------------HEX BYTE ADDRESS --------------
xx00  00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F

0000  2B 78 1A 1C 84 20 03 29 7A 87 49 00 00 1C 83 03
0010  09 15 23 33 43 41 33 68 8B 91 92 87 7B 6C 5C 50
0020  49 5C 6B 63 58 37 28 14 0A 02 0A 00 00 00 00 00
0030  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0040  00 00 00 00 00 00 00 00
0050  00 00 00 00 00                 ERROR CODES &
                                     EEPROM DATA
```

FIG. 6.14—Formatted hex listing for Hypothetical Case 3.

HEX DATA BYTE ADDR	DATA - BYTE VALUE - HX	DEC	BINARY	TRANSLATED MEANING & ENCODING	TRANSLATION FOR THIS HYPOTHETICAL EXAMPLE
0000:	2B	43	00101011	SOFTW IDENT version, level	Version 2, Level B
0001:	78	120	01111000	SOFTW DATE HI yr, month	{199}7, August
0002:	1A	26	00011010	SOFTW DATE LO day	26th day
0003:	1C	28	00011100	TOTAL IGN CYCLE COUNTR, HI BYTE, 256 per count	7168
0004:	84	132	10000100	TOTAL IGN CYCLE COUNTR, LO BYTE, units count, 0-255	+132 =-> 7300, total ign cycles, incl
0005:	20	32	00100000	HISTORY FAULT FLAGS: 13 14 15 16 18 20 21 25	fault 15 in history
0006:	03	3	00000011	HISTORY FAULT FLAGS: 30 33 35 41 42 43 71 72	fault 71,72 in history
0007:	29	41	00101001	CR1 ALG OV ENAB THRESH - DEPLY COMMD TIME 0.5ms/COUNT	20.5 ms
0008:	7A	122	01111010	CR1 ALG ENAB-PEAK G, TIME 0.5ms/COUNT	61.0 ms
0009:	87	135	10000111	CR1 ALG OVER ENAB THRESHOLD TIME 1.0ms/COUNT	135 ms
000A:	49	73	01001001	CR1 PEAK G Accel 0.2G/ count	14.6 G
000B:	00	0	00000000	CR1 HIST FAULT FLAGS: 13 14 15 16 18 20 21 25	No fault in history
000C:	00	0	00000000	CR1 HIST FAULT FLAGS: 30 33 35 41 42 43 71 72	No fault in history
000D:	1C	28	00011100	CR1 IGN CYCLE COUNTR, HI BYTE 256/count	7168
000E:	83	131	10000011	CR1 IGN CYCLE COUNTR, LO BYTE 0-255	+131 =-> 7299, ign cycle @ crash event
000F:	03	3	00000011	CR1 PERIOD 1 ACCEL DATA 0.1G/ count	3 x 0.1 = 0.3G
0010:	09	9	00001001	CR1 PERIOD 2 ACCEL DATA 0.1G/ count	9 x 0.1 = 0.9G
0011:	15	21	00010101	CR1 PERIOD 3 ACCEL DATA 0.1G/ count	21 x 0.1 = 2.1G
0012:	23	35	00100011	CR1 PERIOD 4 ACCEL DATA 0.1G/ count	35 x 0.1 = 3.5G
0013:	33	51	00110011	CR1 PERIOD 5 ACCEL DATA 0.1G/ count	51 x 0.1 = 5.1G
0014:	43	75	01000011	CR1 PERIOD 6 ACCEL DATA 0.1G/ count	75 x 0.1 = 7.5G
0015:	41	65	01000001	CR1 PERIOD 7 ACCEL DATA 0.1G/ count	65 x 0.1 = 6.5G
0016:	33	51	00110011	CR1 PERIOD 8 ACCEL DATA 0.1G/ count	51 x 0.1 = 5.1G
0017:	68	104	01101000	CR1 PERIOD 9 ACCEL DATA 0.1G/ count	104 x 0.1 = 10.4G
0018:	8B	139	10001011	CR1 PERIOD10 ACCEL DATA 0.1G/ count	139 x 0.1 = 13.9G
0019:	91	145	10010001	CR1 PERIOD11 ACCEL DATA 0.1G/ count	145 x 0.1 = 14.5G
001A:	92	146	10010010	CR1 PERIOD12 ACCEL DATA 0.1G/ count	146 x 0.1 = 14.6G
001B:	87	135	10000111	CR1 PERIOD13 ACCEL DATA 0.1G/ count	135 x 0.1 = 13.5G
001C:	7B	123	01111011	CR1 PERIOD15 ACCEL DATA 0.1G/ count	123 x 0.1 = 12.3G
001D:	6C	108	01101100	CR1 PERIOD15 ACCEL DATA 0.1G/ count	108 x 0.1 = 10.8G
001E:	5C	92	01011100	CR1 PERIOD16 ACCEL DATA 0.1G/ count	92 x 0.1 = 9.2G
001F:	50	80	01010000	CR1 PERIOD17 ACCEL DATA 0.1G/ count	80 x 0.1 = 8.0G
0020:	49	73	01001001	CR1 PERIOD18 ACCEL DATA 0.1G/ count	73 x 0.1 = 7.3G
0021:	5C	92	01011100	CR1 PERIOD19 ACCEL DATA 0.1G/ count	92 x 0.1 = 9.2G
0022:	6B	107	01101011	CR1 PERIOD20 ACCEL DATA 0.1G/ count	107 x 0.1 = 10.7G
0023:	63	99	01100011	CR1 PERIOD21 ACCEL DATA 0.1G/ count	99 x 0.1 = 9.9G
0024:	58	88	01011000	CR1 PERIOD22 ACCEL DATA 0.1G/ count	88 x 0.1 = 8.8G
0025:	37	55	00110111	CR1 PERIOD23 ACCEL DATA 0.1G/ count	55 x 0.1 = 5.5G
0026:	28	40	00101000	CR1 PERIOD24 ACCEL DATA 0.1G/ count	40 x 0.1 = 4.0G
0027:	14	20	00010100	CR1 PERIOD25 ACCEL DATA 0.1G/ count	20 x 0.1 = 2.0G
0028:	0A	10	00001010	CR1 PERIOD26 ACCEL DATA 0.1G/ count	10 x 0.1 = 1.0G
0029:	02	2	00000010	CR1 PERIOD27 ACCEL DATA 0.1G/ count	2 x 0.1 = 0.2G
002A:	0A	10	00001010	CR1 x, x, DvrSB, PasSB, LFOcc, RFOcc, LFAd/Ch, RFAd/Ch	Adult Dvr= Unbuckled, No Passenger

FIG. 6.15—Case 3 interpreted data showing one line per address, listing the hexadecimal value, decimal equivalent, binary equivalents, and interpretation of the equivalents with respect to specific formats.

This method accumulates velocity change by utilizing a summation of the incremental velocity change values (average acceleration × segment time). This cumulative velocity change for the data of Fig. 6.14 is graphically illustrated in Fig. 6.16.

Each segment $\Delta V_{segment}$ is calculated using the formula,

$$\Delta V_{segment} = \langle a_{segment} \rangle \, t_{segment}$$

In this case, the $\langle a_{segment} \rangle$, given in Gs, must be multiplied by 32.2 ft/s^2 to determine the acceleration in ft/s^2, after which segment's $\Delta V_{segment}$, having units of ft/s, must be converted to mph or kph. When these values are summed, the resultant sum is the cumulative velocity change experienced at the sensor location during the crash event. This is commonly called the Crash Delta V.

Referring to our graphical summary of this analysis in Fig. 6.16, we can see that the vehicle was traveling at 21.6 mph (34.8 kph) before the single impact. Note that we did not need any mathematical model to achieve this answer.

6.6.3 Checking the Applicability of Haversine Models to Case 3 Velocity Change Data

However, as a check on our methods, let us overlay the assumed symmetric haversine model from Case 2 onto the data in Case 3. Observing this overlay in Fig. 6.17, we can now repeat our model calculation for Case 3's boundary parameters of T_{pulse} = 135 ms and a_{peak} = 14.6 Gs.

$$\Delta V_{event} = 1/2[a_{peak}][t_{pulse}]$$
$$= 0.5 * 470.12 \text{ ft/s}^2 * 0.135 \text{ s} = 31.73 \text{ ft/s}$$
$$= 21.64 \text{ mph } (34.82 \text{ kph})$$

Thus, we can see that the irregular waveform reported in the Case 3 EEPROM incremental acceleration data was actually well characterized by our two-data-point haversine model (T_{pulse} = 135 ms and a_{peak} = 14.6 Gs).

As additional evidence in this crash, we can see an example with ABS Code 23, RF WSS Continuity (open), shown in Fig. 6.18, which saved a freeze frame data indicating vehicle speed at 21 mph. Since this DTC is in the area affected

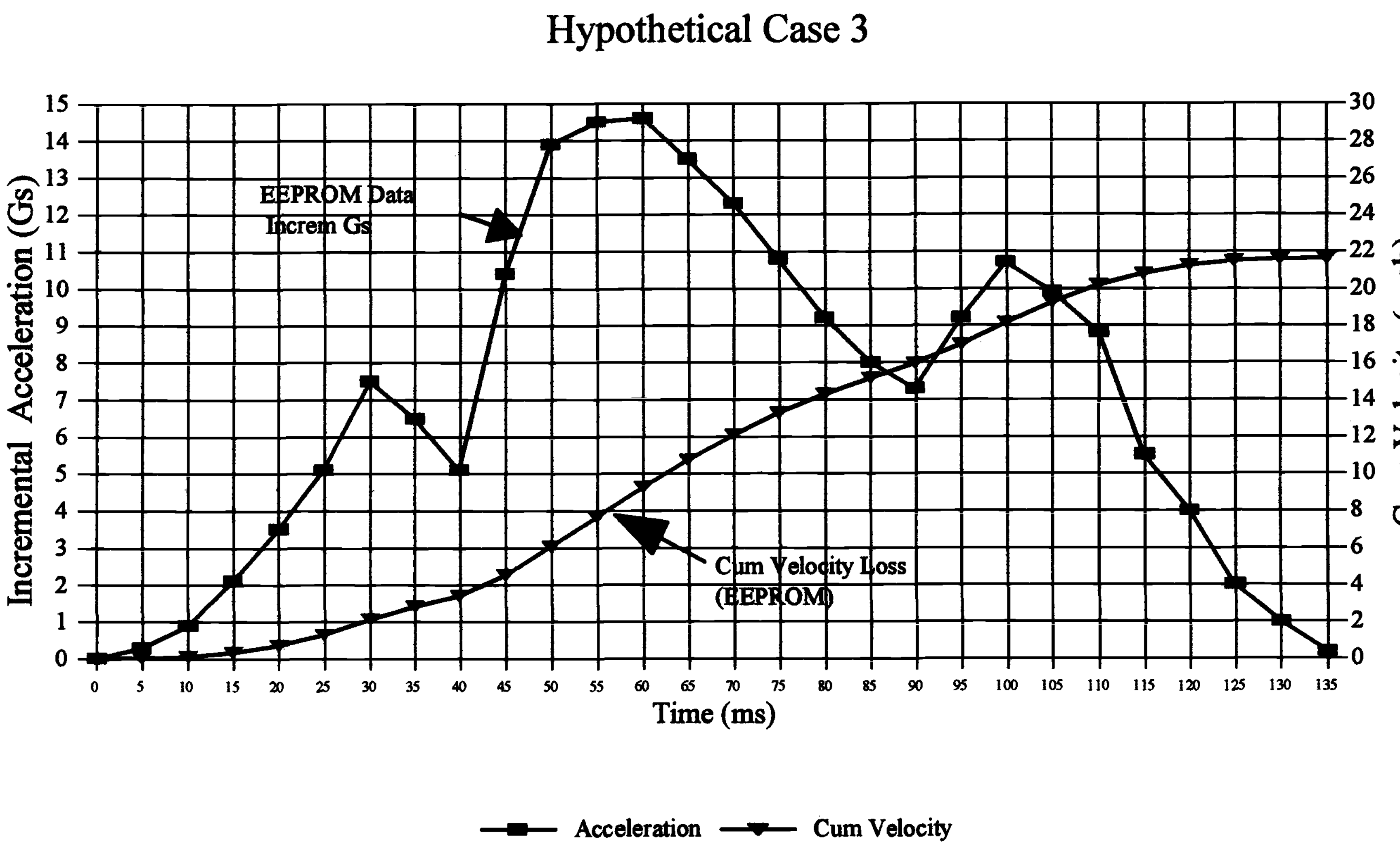


FIG. 6.16—The product of a numeric summation of the incremental acceleration values from the data table in Case 3.

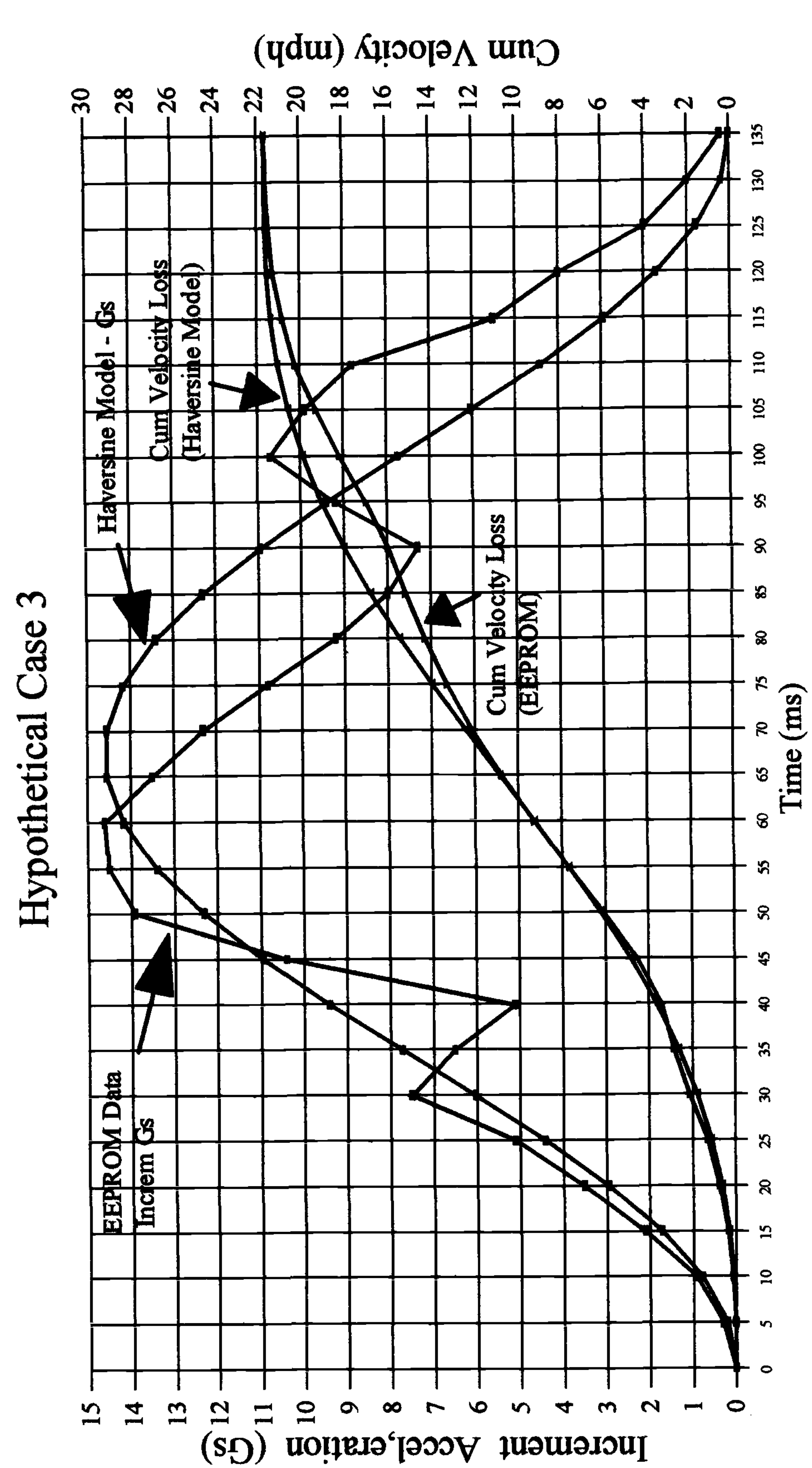


FIG. 6.17—Overlay of the assumed-symmetric haversine model from Case 2 onto the segment summation data in Case 3.

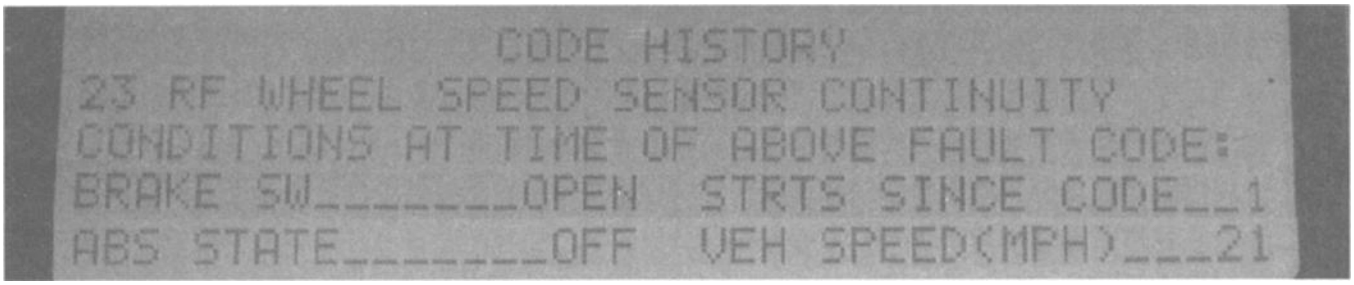


FIG. 6.18—ABS DTC 23 (right front wheel speed sensor) freeze frame record, showing ABS = off, brake not applied and a wheel speed of 21 mph at time of the DTC, which occurred in the immediately previous ignition cycle.

by the frontal crash, it can indicate a strong corroboration of our crash data analysis.

6.7 HYPOTHETICAL CASE 4, ANALYSIS OF A SIMPLE CRASH WHERE CUMULATIVE VELOCITY CHANGE OVER A FIXED PERIOD OF TIME SAMPLES IS RECORDED

In this hypothetical case, the SRS again uses an accelerometer internal to the ECU to detect the crash deceleration condition. This form of ECU integrates each 5 ms period acceleration value to calculate $\Delta V_{segment}$ for each of the 30 segments in the pulse recording period (150 ms). It then adds that $\Delta V_{segment}$ to the accumulated sum of the prior segments and stores the accumulated value at each segment in RAM until after it has fired the air bags. After deployment, it transfers the RAM values to EEPROM, and that is the record we find in our data download. Normally, a safing/arming sensor is also used to confirm proper conditions for air bag deployment. Various other parameters recorded by such ECUs can include seat belt usage, ignition cycle count, system fault status, system electrical parameters and air bag lamp status. Such ECUs can typically record data for one to two crashes.

In this example, we have taken the hypothetical EEPROM data record from such an ECU, shown in Fig. 6.19, and interpreted it in Fig. 6.20.

6.7.1 Evaluation of Case 4 Data In Address Sequence

The data byte at address $0000, $3A, tells us that the software is Version 3, Level A. This parameter was evaluated as a State Encoded value of the hex/binary data (per Chapter 2.6.2, SAE J2178-2:6).

The data byte at address $0001, $6B, tells us that the month and the year of the software release was November 1996. These parameters were evaluated as a State Encoded value of the hex/binary data (per Chapter 2.6.2, SAE J2178-2:6).

The data byte at address $0002, $19 = 25, tells us that the day of the software release was the 25th. This parameter was evaluated as a straight Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4).

The data bytes at addresses $0003 to $0004, $0C84, gives us the value of the ignition cycle counter at the time of our interrogation (3204). From the data bytes at addresses $0009 to $000A, $0C81, which document the ignition counter for the crash, we see that the crash happened at Cycle 3201. We now know that there have been two ignition cycles between the crash cycle and the current cycle. These parameters were evaluated as straight Unsigned Numerics from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4).

The data byte at address $0005, $03, shows us that the ECU was reset once at the factory and once in the field, before the crash. These parameters are evaluated by observing the mask bit position versus the stated condition map (i.e.,

```
HYPOTHETICAL EEPROM DATA LISTING (FORMATTED HEX)

HEX
WORD
ADDRS --------------HEX BYTE ADDRESS --------------
xx00  00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F

0000  3A 6B 19 0C 84 03 10 03 96 0C 81 00 00 35 01 02
0010  06 09 0A 0C 10 15 1D 22 2D 36 44 4A 53 57 5F 60
0020  61 61 61 61 61 61 61 61 61 61 61 61 00 00 00 00
0030  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0040  00 00 00 00 00 00 00 00
0050  00 00 00 00 00                  ERROR CODES &
                                      EEPROM DATA
```

FIG. 6.19—Formatted hex listing for Hypothetical Case 4.

HEX DATA BYTE ADDR	DATA - BYTE VALUE - HX	DEC	BINARY	TRANSLATED MEANING & ENCODING	TRANSLATION FOR THIS HYPOTHETICAL EXAMPLE
0000:	3A	58	00111010	SOFTW IDENT version, level	Version 3, Level A
0001:	6B	107	01101011	SOFTW DATE HI yr, month	{199}6, Nov
0002:	19	25	00011001	SOFTW DATE LO day	25th day
0003:	0C	12	00001100	TOTAL IGN CYCLE COUNTR, HI BYTE, 256 per count	3072
0004:	84	132	10000100	TOTAL IGN CYCLE COUNTR, LO BYTE, units count, 0-255	+132 ==> 3204, total ign cycles, incl
0005:	03	3	00000011	RESET HIST, bits 1-7-field, bit 0=factory reset	Reset @ fact + 1x in field before crash
0006:	10	16	00010000	HISTORY FAULT FLAGS: 13 14 15 16 18 20 21 25	fault 16 in history
0007:	03	3	00000011	HISTORY FAULT FLAGS: 30 33 35 41 42 43 71 72	fault 71, 72 in history
0008:	96	150	10010110	CRASH1 AlgOn--AlgOFF 1 ms/ct	150 x 1 = 150 ms
0009:	0C	12	00001100	CRASH1 IGN CYCLE COUNTR, HI BYTE 256/count	3072
000A:	81	129	10000001	CRASH1 IGN CYCLE COUNTR, LO BYTE 0-255	+129 ==> 3201, ign cycle @ crash event
000B:	00	0	00000000	CRASH1 FAULT FLAGS: 13 14 15 16 18 20 21 25	No faults, this line
000C:	00	0	00000000	CRASH1 FAULT FLAGS: 30 33 35 41 42 43 71 72	No faults, this line
000D:	35	53	00110101	CRASH1 DATA SRS Lmp, ON/OFF ct, cy pr to crash igct	SRS lamp was OFF for 53 ign cycles prior
000E:	01	001	00000001	CRASH1 Sector 1 Delta_V 0.2MPH/count	1 x 0.2 = 00.2 MPH cum
000F:	02	002	00000010	CRASH1 Sector 2 Delta_V 0.2MPH/count	2 x 0.2 = 00.4 MPH cum
0010:	06	006	00000110	CRASH1 Sector 3 Delta_V 0.2MPH/count	6 x 0.2 = 01.2 MPH cum
0011:	09	009	00001001	CRASH1 Sector 4 Delta_V 0.2MPH/count	9 x 0.2 = 01.8 MPH cum
0012:	0A	010	00001010	CRASH1 Sector 5 Delta_V 0.2MPH/count	10 x 0.2 = 02.0 MPH cum
0013:	0C	012	00001100	CRASH1 Sector 6 Delta_V 0.2MPH/count	12 x 0.2 = 02.4 MPH cum
0014:	10	016	00010000	CRASH1 Sector 7 Delta_V 0.2MPH/count	16 x 0.2 = 03.2 MPH cum
0015:	15	021	00010101	CRASH1 Sector 8 Delta_V 0.2MPH/count	21 x 0.2 = 04.2 MPH cum
0016:	1D	029	00011101	CRASH1 Sector 9 Delta_V 0.2MPH/count	29 x 0.2 = 05.8 MPH cum
0017:	22	034	00100010	CRASH1 Sector10 Delta_V 0.2MPH/count	34 x 0.2 = 06.8 MPH cum
0018:	2D	045	00101101	CRASH1 Sector11 Delta_V 0.2MPH/count	45 x 0.2 = 09.0 MPH cum
0019:	36	054	00110110	CRASH1 Sector12 Delta_V 0.2MPH/count	54 x 0.2 = 10.8 MPH cum
001A:	44	068	01000100	CRASH1 Sector13 Delta_V 0.2MPH/count	68 x 0.2 = 13.6 MPH cum
001B:	4A	074	01001010	CRASH1 Sector14 Delta_V 0.2MPH/count	74 x 0.2 = 14.8 MPH cum
001C:	53	083	01010011	CRASH1 Sector15 Delta_V 0.2MPH/count	83 x 0.2 = 16.6 MPH cum
001D:	57	087	01010111	CRASH1 Sector16 Delta_V 0.2MPH/count	87 x 0.2 = 17.4 MPH cum
001E:	5F	095	01011111	CRASH1 Sector17 Delta_V 0.2MPH/count	95 x 0.2 = 19.0 MPH cum
001F:	60	096	01100000	CRASH1 Sector18 Delta_V 0.2MPH/count	96 x 0.2 = 19.2 MPH cum
0020:	61	097	01100001	CRASH1 Sector19 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum
0021:	61	097	01100001	CRASH1 Sector20 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum
0022:	61	097	01100001	CRASH1 Sector21 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum
0023:	61	097	01100001	CRASH1 Sector22 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum
0024:	61	097	01100001	CRASH1 Sector23 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum
0025:	61	097	01100001	CRASH1 Sector24 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum
0026:	61	097	01100001	CRASH1 Sector25 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum
0027:	61	097	01100001	CRASH1 Sector26 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum
0028:	61	097	01100001	CRASH1 Sector27 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum
0029:	61	097	01100001	CRASH1 Sector28 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum
002A:	61	097	01100001	CRASH1 Sector29 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum
002B:	61	097	01100001	CRASH1 Sector30 Delta_V 0.2MPH/count	97 x 0.2 = 19.4 MPH cum

FIG. 6.20—Case 4 interpreted data showing one line per address, listing the hexadecimal equivalent, binary equivalents, and interpretation of the equivalents with respect to specific formats.

a "1" indicates that the condition designated by that physical bit position was true). This interpretation corresponds to a Bit Mapped without Mask Byte format per Chapter 2.6.2, SAE J2178-2:2.

The data bytes at addresses $0006 to $0007, $1003, tell us that there are three faults (DTCs) in history, 16, 71, and 72. Similarly, the data bytes at addresses $000B to $000C, $0000, tell us that there were no faults in history or existing at the time of the crash. These parameters are evaluated by observing the mask bit position versus the stated DTC map (i.e., a "1" indicates that a DTC in that physical bit position was true). This interpretation corresponds to a Bit Mapped without Mask Byte format per Chapter 2.6.2, SAE J2178-2:2.

The data byte at address $0008, $96 = 150, shows us that the algorithm was on (active and above threshold) for 150 ms. This parameter was evaluated as an Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4), with the scale factor = 1.0 ms/count.

The data at addresses $0009 through $000C has been covered above.

The data byte at address $000D, $35 = 53, indicates that the SRS MIL was off for 53 ignition cycles before the crash. This is a combined-format byte. These parameters were evaluated by observing a combination of one mask bit (Bit 7, the leftmost bit), and then evaluating the decimal equivalent of the remaining six bits of hex/binary data (Bits 6 to 0).

The data bytes in addresses $000E through $002B represent 30 periods of accumulated $\Delta V_{segment}$ data. These data are plotted as cumulative Delta V in Fig. 6.21. These parameters were evaluated as Unsigned Numeric values from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4), with the scale factor = 0.2 mph/count.

6.7.2 Discussion of Case 4 Data

Figure 6.21 shows the cumulative Delta V data plotted versus time for the 30 bytes of data spaced 5 ms apart, which creates a 150 ms timeline. This Delta V curve represents the cumulative velocity lost by the vehicle. In a typical single crash event, the vehicle will lose a certain amount of cumulative velocity, and then is at rest. On a graph, the lost velocity appears as an upward sloping line that plateaus at a value equal to the pre-crash velocity. Knowing that the Delta V data stored in the SRS ECU is actually the cumu-

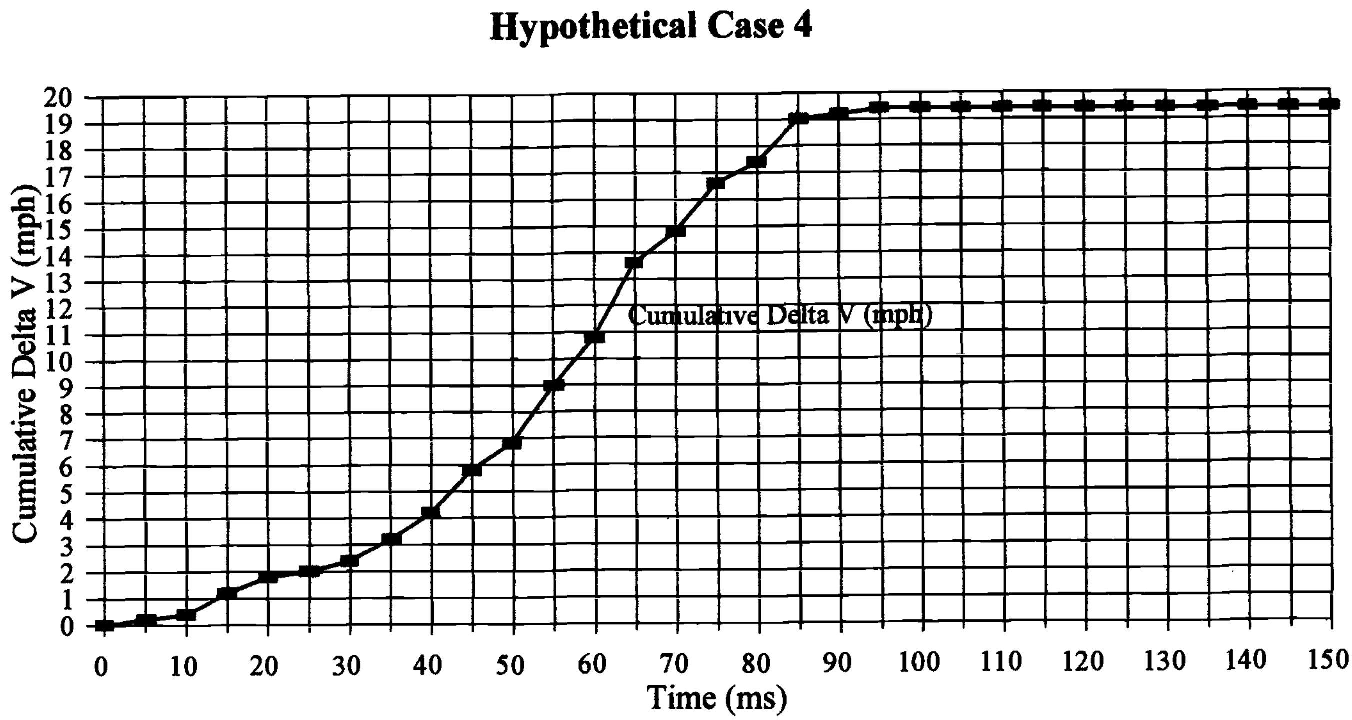


FIG. 6.21—Cumulative Delta V versus time for 30 bytes of data spaced 5 ms apart.

lative velocity lost by the vehicle also allows us to determine the approximate acceleration sensed by the vehicle crash sensor during the crash events. The acceleration is calculated using the formula

$$a = \Delta V/\Delta t.$$

In this case, the ΔV is the difference between each successive velocity data point stored in the SDM in mph, and $\Delta t = 5$ ms, the segment times at which the velocity data was stored. After dividing the velocity by the time, and carefully converting to ft/s^2, the resulting acceleration value can then be divided by 32.2 ft/s^2 to determine the maximum *G*s experienced by the sensor during that time interval. A plot of these $\Delta V/\Delta t$, or acceleration, values is shown in Fig. 6.22.

This type of crash pulse is indicative of a difficult to sense, low speed pole impact. As a check on our methods, let us attempt to create a haversine model for the data of Case 4. Figure 6.23 shows the acceleration data of Fig. 6.22 overlayed with a MathCad™ ksmooth best fit curve. We can see that this best fit curve resembles a not quite symmetric haversine. However, let us use the data in our model to see how close we come to calculating the cumulative ΔV recorded in the EEPROM data. Focusing on this overlay in Fig. 6.23, we can now repeat our model calculation for Case 4's best fit boundary parameters of $T_{pulse} = 100$ ms and $a_{peak} = 18.7$ *G*s.

$$\Delta V_{event} = 1/2[a_{peak}][t_{pulse}]$$

$$= 0.5*602.14 \text{ ft/s}^2*0.100 \text{ s} = 30.107 \text{ ft/s}$$

$$= 20.53 \text{ mph (33.04 kph)}$$

So, we can see that the best fit asymmetric haversine model waveform shown in Fig. 6.23 provides a ΔV estimate about 5.8% (20.53/19.4 mph) higher than the EEPROM data—assuming the EEPROM data to be 100% accurate. Considering all the variables involved, agreement within ±10% confirms the validity of both analyses and is comparable to the error band (precision) expressed in most reconstruction analyses (Day and Hargens 1989; McHenry Software, undated).

One aspect of an investigation in such a case would be whether any potential driver injuries came about because of an improperly timed deployment, or because of improper contact with the air bag.

In this case, the EEPROM data allow us to compile an analysis of crash timing and dynamics. Figure 6.22 shows the vehicle deceleration derived from the EEPROM Delta V data. We can further derive that the air bag deployment was commanded at 45 ms after impact by sensor algorithm specifications and looking at the area under the acceleration algorithm curve in Fig. 6.22.

Figure 6.24 is a composite of Figs. 6.21 through 6.23 and allows us to compile the following crash timing analysis:

1. Assumptions are as follows:
   a) The driver air bag is tethered at 11 in. (27.5 cm) max throw.
   b) The driver air bag is electrically ignited and the envelope breaks out of its fascia 5 ms after the leading edge of the firing pulse.
   c) After breakout, the driver air bag envelope takes 15 ms to reach its max tethered throw of 11 in (27.5 cm), and it stays stable or deflating for the next 100 to 150 ms.
   d) At t_0 (impact), the operator's face is 17 in (42.5 cm) from the steering wheel.
   e) For this analysis, the operator's head is treated as a free body.

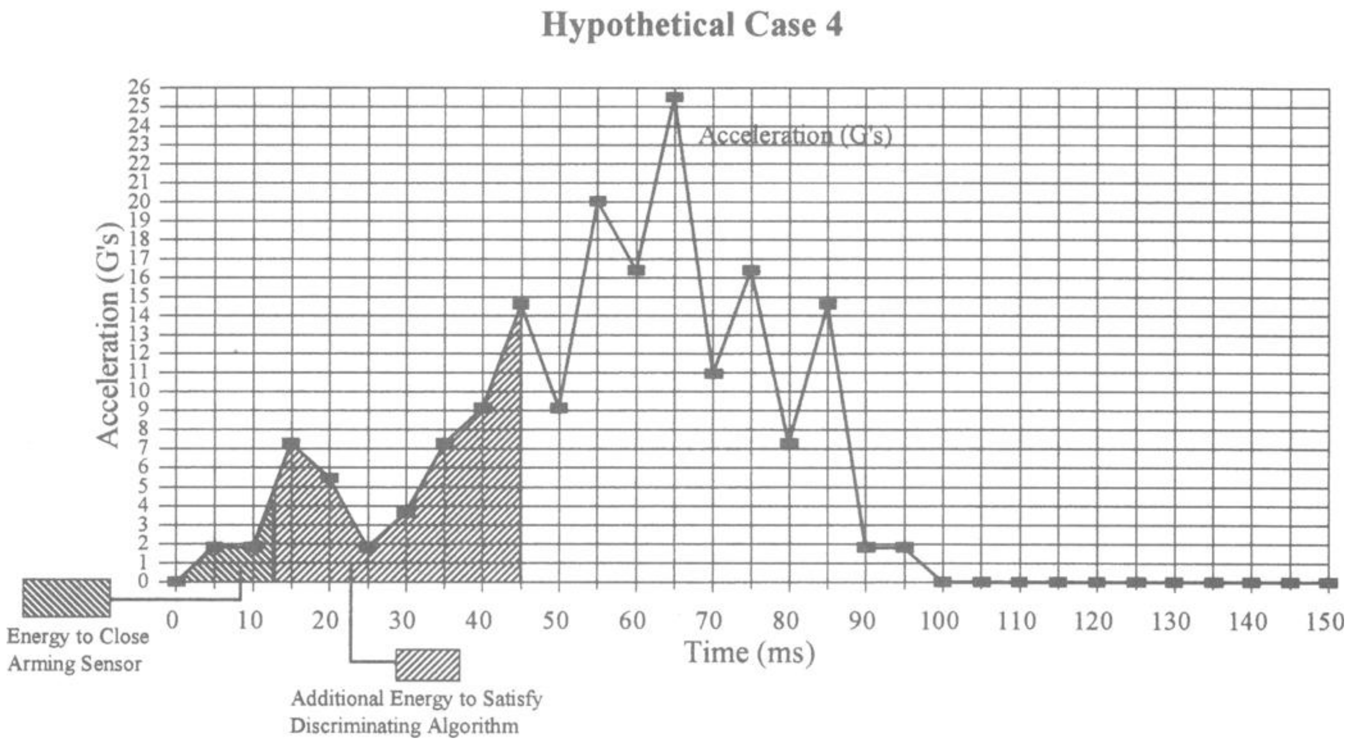


FIG. 6.22—Acceleration derived by evaluating $\Delta V/\Delta t$ from the data in Fig. 6.21.

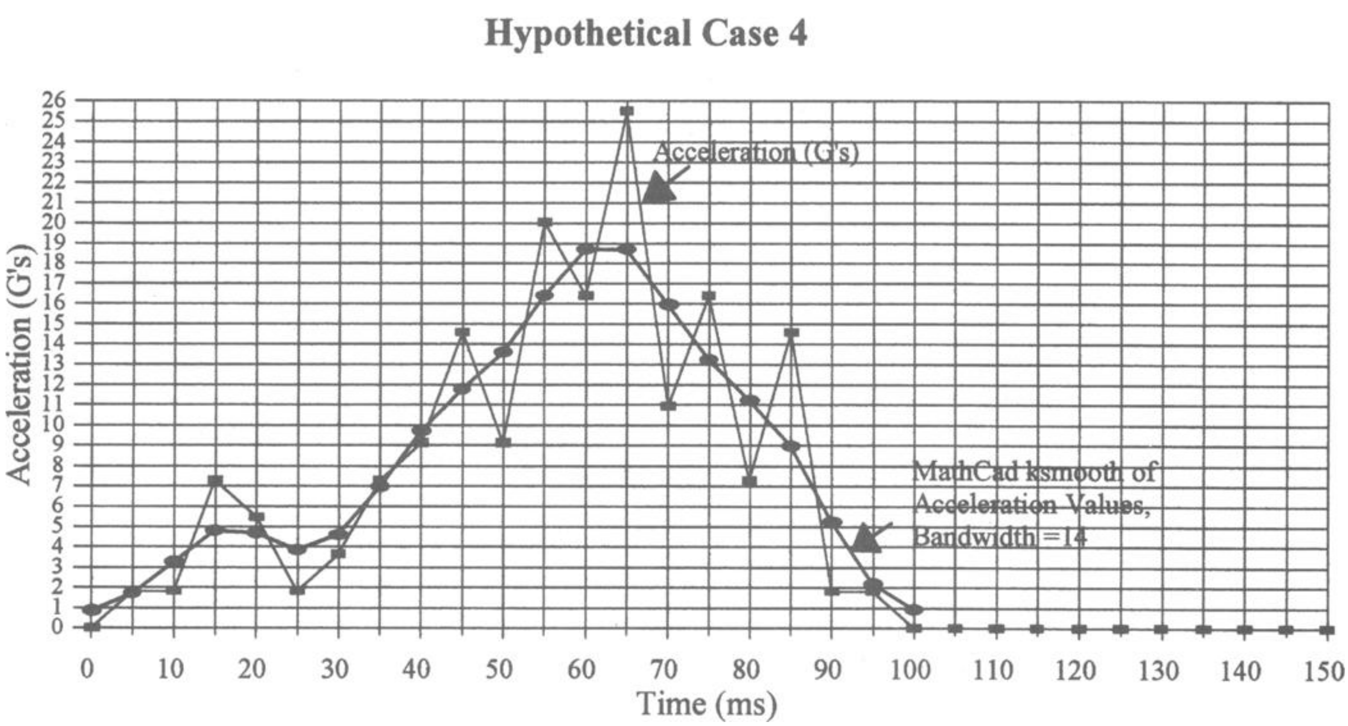


FIG. 6.23—Smoothed fit to Fig. 6.22 acceleration derived by evaluating $\Delta V/\Delta t$ from Fig. 6.21.

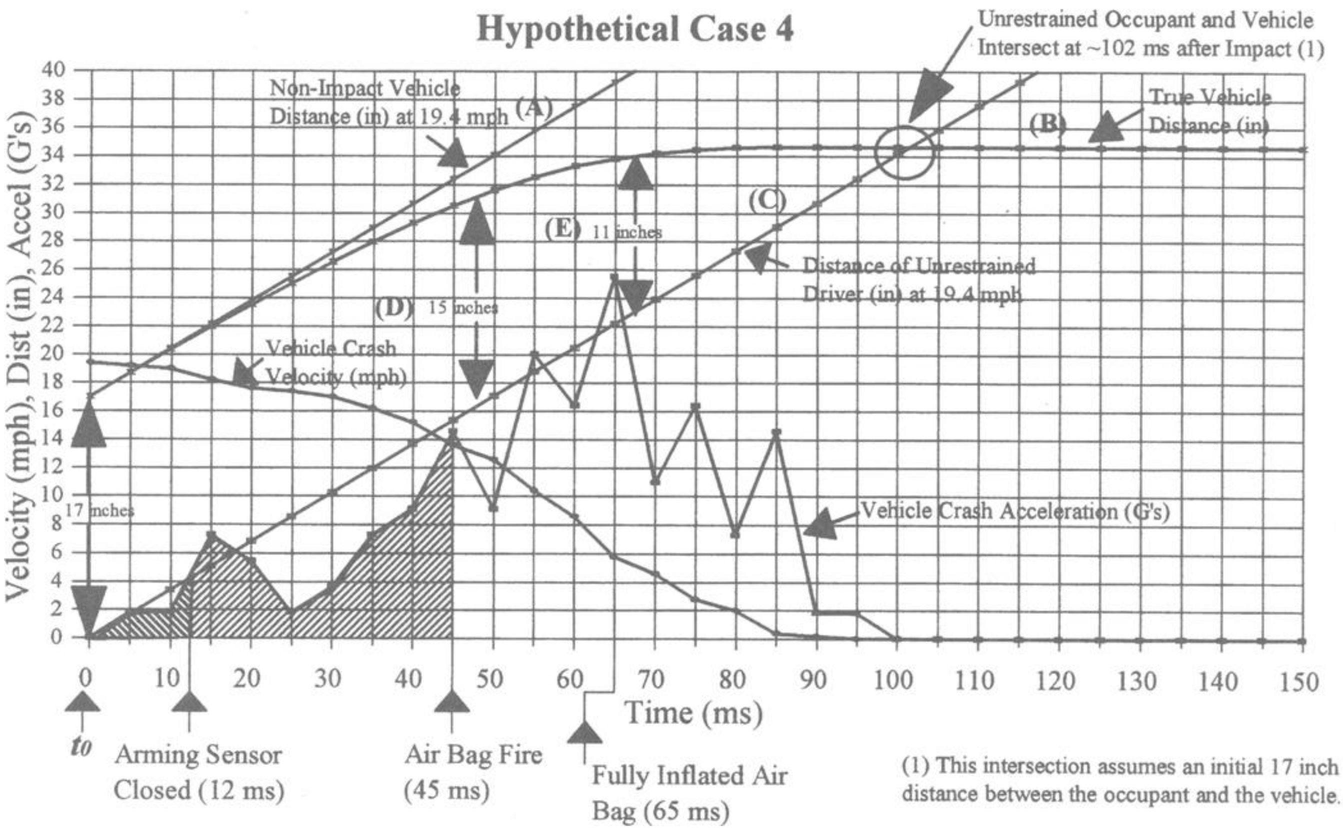


FIG. 6.24—Composite data from Figs. 6.21 through 6.23, plus analysis of occupant closing distance versus time. Note how distance from the driver (free body, C) to vehicle (B) is slowly closing from 17 in. at t_0 (actually from pre-impact to $t_0 + \varepsilon$), to 15 in. at 48 ms (D), to 11 in. at 67 ms (E).

f) The arming sensor closes for a cumulative Delta V of 1.5 mph at 12 ms.[11]

g) The algorithm commands air bag fire for a cumulative Delta V of 6 mph at its location, and the arming sensor must be closed. Examining our data, we see that this occurs at 45 ms after the algorithm started accumulating data.

2. From pre-impact through t_0, both the operator's face and the vehicle are moving at the full Crash Delta V of 19.4 mph (31.22 kph).
3. At $t_0 + \varepsilon$,[12] the operator and the vehicle are still moving at 19.4 mph (31.22 kph). The distance moved after t_0 can be directly integrated as $V \times \Delta t$. This appears as a straight line for both the vehicle steering wheel (A), and the driver (C). Note that both are straight lines with an offset (separation) of 17 in. (42.5 cm), representing the driver's initial distance from the steering wheel.
4. As crash time progresses, the unrestrained operator travel distance proceeds in a straight line, described as the summation of products $\Sigma V \times \Delta t$ – the line (C) starting at 0 in (0 cm).
5. However, as the vehicle crash impact proceeds, the vehicle's velocity is slowed in proportion to the impact force, and the consequent deceleration produced by that force over the crash time.
6. As the vehicle velocity slows, its travel distance cannot proceed along the straight line (A). Its travel distance per time decreases, and is described by Curve (B). The magnitude of this distance-decrease is the second integral of the acceleration as discussed in Case 1 and illustrated in Fig. 6.10.
7. This diminishing vehicle travel distance (B) versus the linear travel distance of the unrestrained driver (C) causes a closing of the distance from the driver to the steering wheel (fixed vehicle coordinate). This is shown as slowly closing from 17 in. at t_0 (actually, pre-impact through $t_0 + \varepsilon$), to 15 in. at 48 ms (D), to 11 in. at 67 ms (E), to 0 in. at 102 ms (intersection).
8. Thus, with no air bag, there will be an intersection of the unrestrained driver and the steering wheel, where (B) intersects (C). For the parameters of this accident, this intersection would occur at approximately 102 ms after impact (shown as the circled intersection on Fig. 6.24). However, we are evaluating whether the air bag system served to protect the driver and prevent this (hard) intersection, and this is done as follows:

a) From our assumptions, we know that it took approximately 12 ms after impact for the arming sensor to close, and we know that the crash algorithm (or sensor)

[11] This may also be thought of as an accumulated energy (force × time), shown on our figures as integrated acceleration area over time. Also see additional discussion in Chapter 5.4.2.

[12] A common convention is to use the symbol epsilon, ε, to represent a very small incremental value. In this case, we are considering a very small unit of time after t_0.

would have fired the air bags at 45 ms after impact. These times are shown on Figs. 6.24 and 6.25.

b) If the air bag fires at 45 ms, and has a 20 ms breakout + inflation time (5 + 15 ms) to first maximum throw, we can evaluate the driver position with respect to the vehicle coordinates at the first maximum throw.
c) We now know the time to the air bag's first maximum throw occurs at 65 ms after impact (45 ms to fire + 20 ms to achieve first max throw). At this time, the driver position with respect to the steering wheel has decreased from 17 in. (42.5 cm) to 11.6 in. (29.5 cm).
d) At this time (65 ms), the driver air bag is at its maximum leading edge throw of 11 in. (27.5 cm), and its tethers hold it there.
e) This leaves a gap of 0.6 inches (1.5 cm) between the driver and the leading edge of the air bag at its maximum initial throw (11.6 in. to 11 in.). After that point, the air bag is stable and/or deflating, with minimal or zero leading edge velocity (for the next 100 to 150 ms, the period under consideration). The air bag has, for the moment, become an 11 in. (27.5 cm) extension of the steering wheel. The inflating air bag is shown as curve segment F1 in Fig. 6.25. Note that at first maximum inflation, the air bag has not yet contacted the driver. The air bag leading edge now follows the vehicle travel contour (B), and this portion of (inflated) air bag travel is shown as curve segment F2 in Fig. 6.25.
f) Following curve segment F2 in Fig. 6.25, with the air bag 11 in. (27.5 cm) out from the steering wheel, we can see that the driver will first contact the inflated and tethered air bag at 67 ms.[13]
g) Thus, in this case, the air bag has safely deployed and has been at full tethered extension approximately 2 ms before driver contact. At this point the air bag is stable and/or deflating, with minimal or zero leading edge velocity. Therefore, we have a safely deployed air bag properly protecting the driver during the deceleration ride down in a difficult to sense, pole impact type collision (low Delta V and extended timing).
h) A global visualization of this analysis is shown in the time sequences of Fig. 6.1, which show a proper and expected crash/deploy timing scenario, where the occupant's first contact with the air bag envelope is past the time of peak inflation, and continues during the deflation sequence (approximately 70 to 120 ms).

6.8 HYPOTHETICAL CASE 5, ANALYSIS OF A COMPLEX CRASH WHERE CUMULATIVE VELOCITY CHANGE OVER A FIXED PERIOD OF TIME SAMPLES IS RECORDED

In this hypothetical case, the SRS again uses an accelerometer internal to the ECU to detect the crash deceleration condition. As in Case 4, this form of ECU integrates each 5 ms period acceleration values to calculate $\Delta V_{segment}$ for each of 30 segments in its pulse recording period (150 ms). It then adds that $\Delta V_{segment}$ to the accumulated sum of the prior segments and stores the accumulated value at each segment in RAM until after it has fired the air bags. After deployment, it transfers the RAM values to EEPROM, and that is the record we find in our data download. Normally, a safing/arming sensor is also used to confirm proper conditions for air bag deployment. Various other parameters recorded by such ECUs can include seat belt usage, ignition cycle count, system fault status, system electrical parameters, and air bag lamp status. Such ECUs can typically record data for one to two crashes.

This example expands upon Case 4 in that we have a deceleration and an acceleration in the saved data record. In our Case 5 analysis we will see how we account for this by reference to force vector directions on the vehicle longitudinal axis (the X axis).

In this example, we have taken the hypothetical EEPROM data record from such an ECU, shown in Fig. 6.26, and interpreted it in Fig. 6.27.

6.8.1 Evaluation of Case 5 Data In Address Sequence

The data byte at address $0000, $3A, tells us that the software is Version 3, Level A. This parameter was evaluated as a State Encoded value of the hex/binary data (per Chapter 2.6.2, SAE J2178-2:6).

The data byte at address $0001, $6B, tells us that the month and the year of the software release was November 1996. These parameters were evaluated as a State Encoded value of the hex/binary data (per Chapter 2.6.2, SAE J2178-2:6).

The data byte at address $0002, $19, tells us that the day of the software release was the 25th. This parameter was evaluated as a straight Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4).

The data bytes at addresses $0003 to $0004, $0C84, gives us the value of the ignition cycle counter at the time of our interrogation (3204). From the data bytes at addresses $0009 to $000A, $0C81, which document the ignition counter for the crash, we see that the crash happened at Cycle 3201. We now know that there have been two ignition cycles between the crash cycle and the current cycle. These parameters were evaluated as straight Unsigned Numerics from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4).

The data byte at address $0005, $03 = 03, shows us that the ECU was reset once at the factory and once in the field, before the crash. These parameters are evaluated by observing the mask bit position versus the stated condition map (i.e., a "1" indicates that the condition designated by that physical bit position was true). This interpretation corresponds to a Bit Mapped without Mask Byte format per Chapter 2.6.2, SAE J2178-2:2.

The data bytes at addresses $0006 to $0007, $1003, tell us that there are three faults (DTCs) in history, 16, 71, and 72. Similarly, the data bytes at addresses $000B to $000C, $0000, tell us that there were no faults in history or existing at the time of the crash. These parameters are evaluated by observing the mask bit position versus the stated DTC map (i.e., a "1" indicates that a DTC in that physical bit position was

[13] Recall that this is also clearly compliant with the intent of the 5-30 rule (industry guideline).

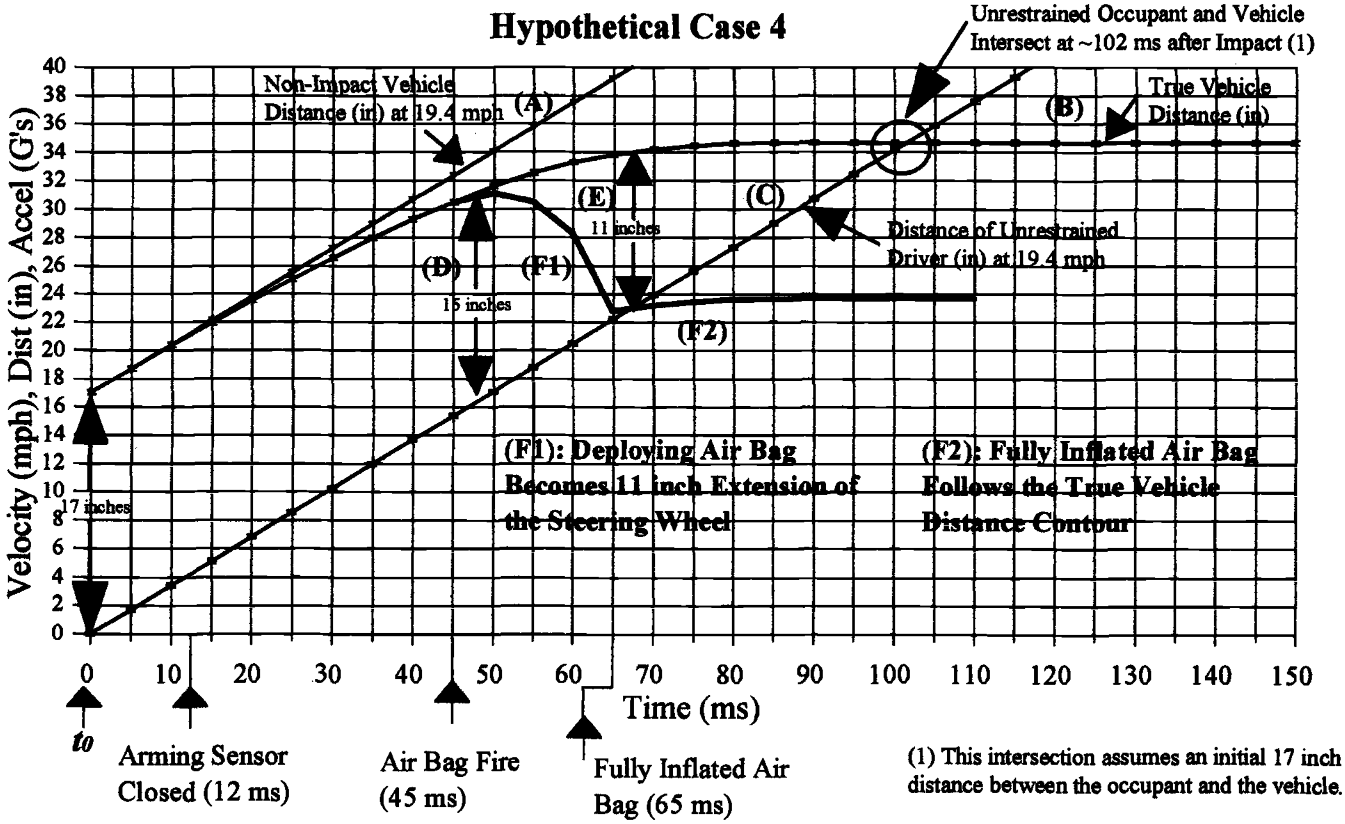


FIG. 6.25—Composite data of Fig. 6.24 with occupant to driver air bag leading edge analysis superimposed. Note that the first driver (free body) contact with the air bag leading edge is at the air bag tether limit of 11 in. (E), which occurs at 67 ms after t_0 (first impact contact).

```
HYPOTHETICAL EEPROM DATA LISTING (FORMATTED HEX)

HEX
WORD
ADDRS  ---------------HEX BYTE ADDRESS ---------------
xx00   00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F

0000   3A 6B 19 0C 84 03 10 03 96 0C 81 00 00 35 01 02
0010   06 09 0A 0C 10 15 1D 22 2D 36 44 4A 53 57 5F 5F
0020   5E 5C 57 52 4E 49 43 3E 3C 3B 3B 3B 00 00 00 00
0030   00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0040   00 00 00 00 00 00 00 00
0050   00 00 00 00 00               ERROR CODES &
                                    EEPROM DATA
```

FIG. 6.26—Formatted hex listing for Hypothetical Case 5.

true). This interpretation corresponds to a Bit Mapped without Mask Byte format per Chapter 2.6.2, SAE J2178-2:2.

The data byte at address $0008, $96 = 150, shows us that the algorithm was on (active and above threshold) for 150 ms. This parameter was evaluated as an Unsigned Numeric from the hex/binary data (per Chapter 2.6.2, SAE J2178-2: 4), with the scale factor = 1.0 ms/count).

The data at addresses $0009 through $000C has been covered above.

The data byte at address $000D, $35 = 53, indicates that the SRS MIL was off for 53 ignition cycles before the crash. This is a combined-format byte. These parameters were evaluated by observing a combination of one mask bit (Bit 7, the leftmost bit), and then evaluating the decimal equivalent of the remaining six bits of hex/binary data (Bits 6 to 0).

The data bytes in addresses $000E through $002B represent 30 periods of accumulated $\Delta V_{segment}$ data. These data are plotted as cumulative Delta V in Fig. 6.21. These parameters

HEX DATA BYTE ADDR	DATA - BYTE VALUE - HX	DEC	BINARY	TRANSLATED MEANING & ENCODING	TRANSLATION FOR HYPOTHETICAL EXAMPLE 5
0000:	3A	58	00111010	SOFTW IDENT version, level	Version 3, Level A
0001:	6B	107	01101011	SOFTW DATE HI yr, month	{199}6, Nov
0002:	19	25	00011001	SOFTW DATE LO day	25th day
0003:	0C	12	00001100	TOTAL IGN CYCLE COUNTR, HI BYTE, 256 per count	3072
0004:	84	132	10000100	TOTAL IGN CYCLE COUNTR, LO BYTE, units count, 0-255	+132 =-> 3204, total ign cycles, incl
0005:	03	3	00000011	RESET HIST, bits 1-7-field, bit 0=factory reset	Reset @ fact + 1x in field before crash
0006:	10	16	00010000	HISTORY FAULT FLAGS: 13 14 15 16 18 20 21 25	fault 16 in history
0007:	03	3	00000011	HISTORY FAULT FLAGS: 30 33 35 41 42 43 71 72	fault 43, 72 in history
0008:	96	150	10010110	CRASH1 AlgOn--AlgOFF 1 ms/ct	150 x 1 = 150 ms
0009:	0C	12	00001100	CRASH1 IGN CYCLE COUNTR, HI BYTE 256/count	3072
000A:	81	129	10000001	CRASH1 IGN CYCLE COUNTR, LO BYTE 0-255	+129 =-> 3201, ign cycle @ crash event
000B:	00	0	00000000	CRASH1 FAULT FLAGS: 13 14 15 16 18 20 21 25	No faults, this line
000C:	00	0	00000000	CRASH1 FAULT FLAGS: 30 33 35 41 42 43 71 72	No faults, this line
000D:	35	53	00110101	CRASH1 DATA SRS Lmp, ON/OFF ct, cy pr to crash igct	SRS lamp = OFF for 53 ign cycles prior
000E:	01	001	00000001	CRASH1 Sector 1 Delta_V 0.2MPH/count	1 x 0.2 = 00.2 MPH cum
000F:	02	002	00000010	CRASH1 Sector 2 Delta_V 0.2MPH/count	2 x 0.2 = 00.4 MPH cum
0010:	06	006	00000110	CRASH1 Sector 3 Delta_V 0.2MPH/count	6 x 0.2 = 01.2 MPH cum
0011:	09	009	00001001	CRASH1 Sector 4 Delta_V 0.2MPH/count	9 x 0.2 = 01.8 MPH cum
0012:	0A	010	00001010	CRASH1 Sector 5 Delta_V 0.2MPH/count	10 x 0.2 = 02.0 MPH cum
0013:	0C	012	00001100	CRASH1 Sector 6 Delta_V 0.2MPH/count	12 x 0.2 = 02.4 MPH cum
0014:	10	016	00010000	CRASH1 Sector 7 Delta_V 0.2MPH/count	16 x 0.2 = 03.2 MPH cum
0015:	15	021	00010101	CRASH1 Sector 8 Delta_V 0.2MPH/count	21 x 0.2 = 04.2 MPH cum
0016:	1D	029	00011101	CRASH1 Sector 9 Delta_V 0.2MPH/count	29 x 0.2 = 05.8 MPH cum
0017:	22	034	00100010	CRASH1 Sector10 Delta_V 0.2MPH/count	34 x 0.2 = 06.8 MPH cum
0018:	2D	045	00101101	CRASH1 Sector11 Delta_V 0.2MPH/count	45 x 0.2 = 09.0 MPH cum
0019:	36	054	00110110	CRASH1 Sector12 Delta_V 0.2MPH/count	54 x 0.2 = 10.8 MPH cum
001A:	44	068	01000100	CRASH1 Sector13 Delta_V 0.2MPH/count	68 x 0.2 = 13.6 MPH cum
001B:	4A	074	01001010	CRASH1 Sector14 Delta_V 0.2MPH/count	74 x 0.2 = 14.8 MPH cum
001C:	53	083	01010011	CRASH1 Sector15 Delta_V 0.2MPH/count	83 x 0.2 = 16.6 MPH cum
001D:	57	087	01010111	CRASH1 Sector16 Delta_V 0.2MPH/count	87 x 0.2 = 17.4 MPH cum
001E:	5F	095	01011111	CRASH1 Sector17 Delta_V 0.2MPH/count	95 x 0.2 = 19.0 MPH cum
001F:	5F	095	01011111	CRASH1 Sector18 Delta_V 0.2MPH/count	95 x 0.2 = 19.0 MPH cum
0020:	5E	094	01011110	CRASH1 Sector19 Delta_V 0.2MPH/count	94 x 0.2 = 18.8 MPH cum
0021:	5C	092	01011100	CRASH1 Sector20 Delta_V 0.2MPH/count	92 x 0.2 = 18.4 MPH cum
0022:	57	087	01010111	CRASH1 Sector21 Delta_V 0.2MPH/count	87 x 0.2 = 17.4 MPH cum
0023:	52	082	01010010	CRASH1 Sector22 Delta_V 0.2MPH/count	82 x 0.2 = 16.4 MPH cum
0024:	4E	078	01001110	CRASH1 Sector23 Delta_V 0.2MPH/count	78 x 0.2 = 15.6 MPH cum
0025:	49	073	01001001	CRASH1 Sector24 Delta_V 0.2MPH/count	73 x 0.2 = 14.6 MPH cum
0026:	43	067	01000011	CRASH1 Sector25 Delta_V 0.2MPH/count	67 x 0.2 = 13.4 MPH cum
0027:	3E	062	00111110	CRASH1 Sector26 Delta_V 0.2MPH/count	62 x 0.2 = 12.4 MPH cum
0028:	3C	060	00111100	CRASH1 Sector27 Delta_V 0.2MPH/count	60 x 0.2 = 12.0 MPH cum
0029:	3B	059	00111011	CRASH1 Sector28 Delta_V 0.2MPH/count	59 x 0.2 = 11.8 MPH cum
002A:	3B	059	00111011	CRASH1 Sector29 Delta_V 0.2MPH/count	59 x 0.2 = 11.8 MPH cum
002B:	3B	059	00111011	CRASH1 Sector30 Delta_V 0.2MPH/count	59 x 0.2 = 11.8 MPH cum

FIG. 6.27—Case 5 interpreted data showing one line per address, listing the hexadecimal value, decimal equivalent, binary equivalents, and interpretation of the equivalents with respect to specific formats.

were evaluated as Unsigned Numeric values from the hex/binary data (per Chapter 2.6.2, SAE J2178-2:4), with the scale factor = 0.2 mph/count).

6.8.2 Discussion of Case 5 Data

Figure 6.28 shows the cumulative Delta V data plotted versus time for the 30 bytes of data spaced 5 ms apart, which creates a 150 ms timeline. This Delta V curve represents the cumulative velocity lost by the vehicle. In a typical single crash event, the vehicle will lose a certain amount of cumulative velocity, and then is at rest. However, on this graph, the cumulative Delta V curve appears to show that the vehicle lost a certain amount of cumulative velocity, 19 mph (30.58 kph), and then reaccelerated, gaining back some of its lost velocity before coming to rest in between 140 and 150 ms. On Fig. 6.28, the lost velocity appears as an upward sloping line, followed by a downward sloping line that indicates regained velocity or self reacceleration, and finally stabilizing at 11.8 mph (18.99 kph). If this were literally true, this would be a very unique crash. However, let us now apply some common sense logic to these data.

First, the vehicle crash record stops, because of data limitations, at 150 ms. A null velocity change record in any segment means that the vehicle speed is not changing, but not that it has necessarily stopped. The subject vehicle cumulative Delta V record shows a stable segment velocity, 11.8 mph (18.99 kph), between 140 to 150 ms, or two sample periods.

Accepting that self reacceleration is a very unlikely scenario, the regained velocity is indicative of one of two scenarios: (1) the car was pushed forwards after initial impact, or (2) the car spun around after initial impact and proceeded in the same direction but with the rear of the car leading.

Scenario 1 fits with the known subject accident facts, i.e., the Subject Car (Vehicle 1) rear-ended a second vehicle (Vehicle 2) stopped in traffic. Then a third vehicle (Vehicle 3) impacted the combined pair (Vehicles 1 and 2), propelling the combined pair forward, until an eventual continued deceleration (later than our time line record) brings the combination to rest. Because the crash detecting accelerometer is actually bidirectional (along the + and − X axis), the Vehicle 3 impact with the combined Vehicles 1 and 2 pair

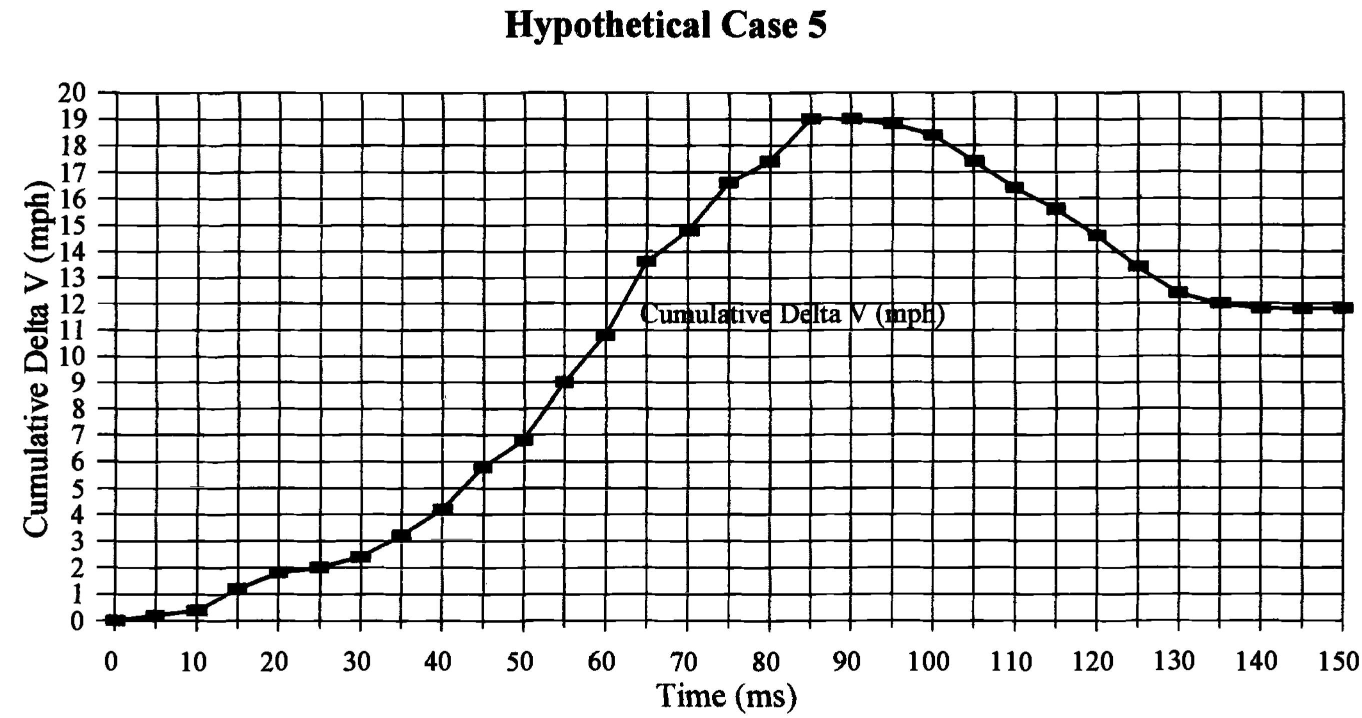


FIG. 6.28—Case 5 cumulative velocity change (Delta V) as reported in the ECU EE-PROM.

caused the accelerometer to be stimulated in its +X direction. This caused it to report a velocity gain instead (downward sloping part of the curve in Fig. 6.28), subtracting from the prior reported cumulative Delta V.

Scenario 2 is unlikely because it would require an angular acceleration rate unobtainable even in the entire amount of time recorded in the EEPROM data (150 ms). A time period more consistent with 180 degrees of vehicle angular rotation would be 500 ms or longer.

Using this new information, Fig. 6.28 was annotated to show more clearly the portions of the recorded curve belonging to each impact. This is shown in Fig. 6.29.

The reader should note that the above analysis applies to the subject moving vehicle (Vehicle 1) impacting a stopped vehicle (Vehicle 2), and then that vehicle pair being reaccelerated by the impact of a third vehicle (Vehicle 3). Because we are only viewing velocity change data, the whole analysis may also apply to that set of vehicles with a translated absolute velocity set, where the initial Vehicle 2 speed was not zero (i.e., 10, 20, 30, mph, etc.).

6.8.3 Checking the Applicability of Haversine Models to Case 5 Velocity Change Data

Now, using the plot of the Delta V (Fig. 6.29), we can plot an approximate acceleration map corresponding to what the vehicle crash accelerometer sensed during the crash event. The segment accelerations are calculated using the formula

$$a_{\text{segment}} = \Delta V / \Delta t$$

for each 5 ms segment.

Performing this calculation, and correcting for units, we have plotted the approximate sensor acceleration in *G*s in Fig. 6.30.

As a check on our methods, let us attempt to create a haversine model for the corrected data of Case 5. Figure 6.31 shows the acceleration data of Fig. 6.30 overlayed with a MathCad™ ksmooth best fit curve. We can see that this best fit curve resembles a not quite symmetric haversine. However, let us use the data in our model to see how close we come to calculating the cumulative ΔV recorded in the EEPROM data. Observing this overlay in Fig. 6.30, we can now repeat our model calculation for Case 5's best fit boundary parameters, this time using two (additive) deceleration models.

The first model has $T_{\text{pulse}} = 90$ ms, $a_{\text{peak}} = 18.7$ *G*s

The second model has $T_{\text{pulse}} = 55$ ms, $a_{\text{peak}} = -9.3$ *G*s. Then:

$$\Delta V_{\text{event}} = 1/2[a_{\text{peak}}][t_{\text{pulse}}]$$

$$\Delta V_1 = 0.5*602.14 \text{ ft/s}^2*0.090 \text{ s}$$

$$= 27.09 \text{ ft/s} = 18.47 \text{ mph } (29.73 \text{ kph})$$

$$\Delta V_2 = 0.5* - 299.46 \text{ ft/s}^2*0.055 \text{ s}$$

$$= -8.24 \text{ ft/s} = -5.62 \text{ mph } (-9.04 \text{ kph})$$

Adding these models algebraically, we have a cumulative Delta V of 18.47 − 5.62 = 12.85 mph (20.68 kph).

Therefore, we can see that our cumulative best fit asymmetric haversine model waveforms shown in Fig. 6.31 provide an end of record residual velocity estimate of 12.85/11.8 mph, or about 8.9% higher than our segment-reconstructed

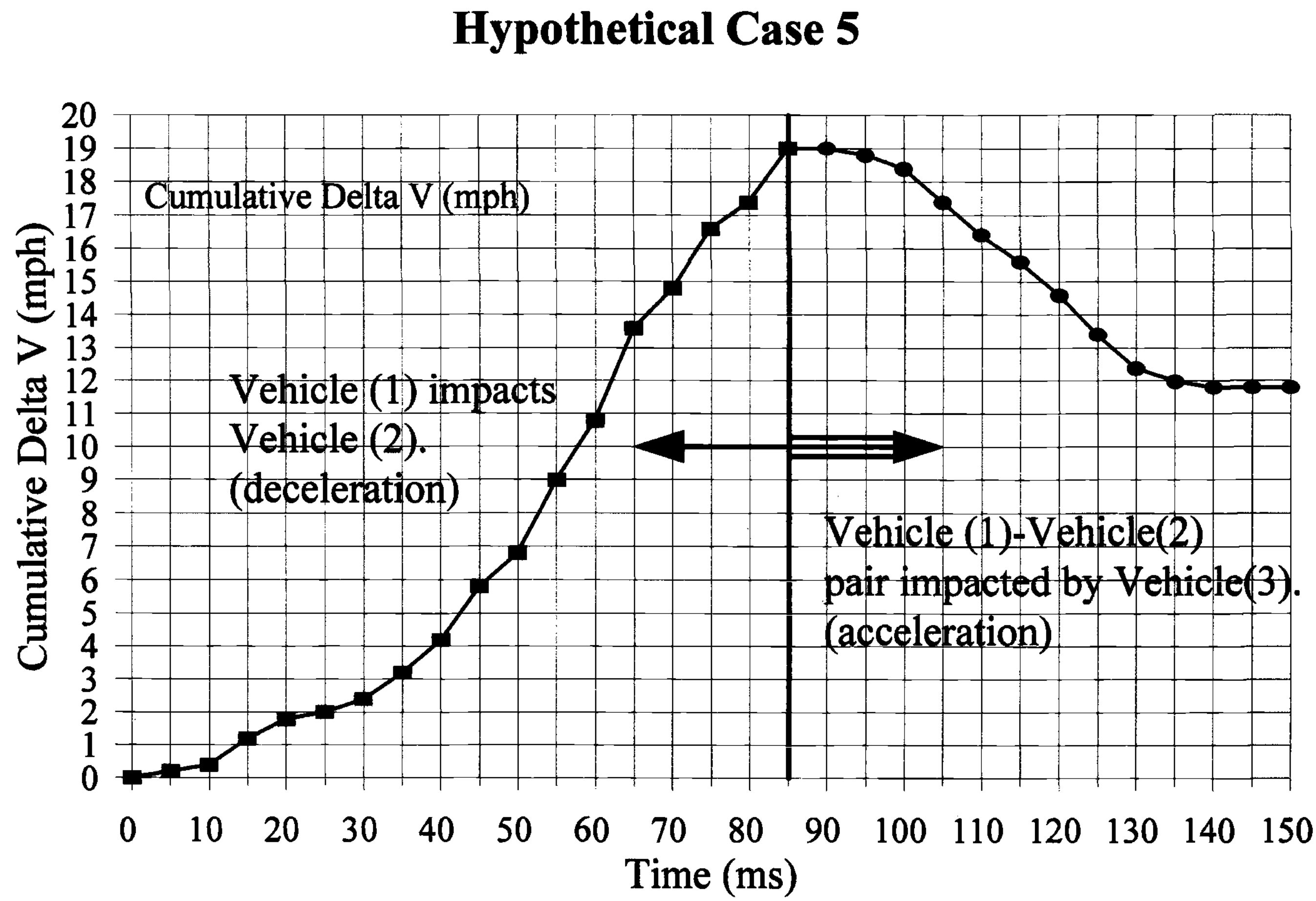


FIG. 6.29—Case 5 cumulative velocity change (Delta V) with separation of crash pulse sections (frontal impact vs. rear end impact).

Delta V data shows. Considering all the variables involved, agreement within ±10% confirms the validity of both analyses, and fall within the accepted 10% tolerances for modeling and reconstruction (Day, McHenry Review). This also shows how both acceleration and deceleration waveforms can be modeled in a similar manner with similar accuracy.

6.9 CASE 6, ANALYSIS OF PRE-EVENT VEHICLE STATUS AND CUMULATIVE VELOCITY CHANGE BEFORE AND AFTER IMPACT FOR A REAL CRASH EVENT

This case continues the analysis of the 1999 model year vehicle crash introduced in Chapter 3, and shown in Figs. 3.22 to 3.24. In Chapter 3, we found that the crash velocity change (Delta V) data were not provided by the CDR, and we reported that. However, in this example, we will show that we can actually interpret the CDR hexadecimal data list to determine the Delta V, and we will discuss two necessary adjustments to that Delta V to determine the true impact velocity along the PDOF.

6.9.1 Crash Vehicle Hexadecimal Data Delta V Interpretation

The CDR hexadecimal information was interpreted as follows:

1. The crash velocity change data contains 15 samples of cumulated velocity change data, recorded every 10 ms, for a 150 ms Delta V record. The Delta V record from the 1999 vehicle (Fig. 3.22) was interpreted as shown in Fig. 6.32.
2. This interpreted EEPROM record indicates a maximum Delta V of approximately 6.1 mph;[14] however, since the SDM does not start to record Delta V values until after algorithm enable (AE), the initial change in longitudinal (–X axis) velocity of the vehicle from impact to algorithm enable is not recorded in the Delta V data. In other words, before time zero (algorithm enable) on the Crash 1 Delta V graph, there is an amount of lost velocity that is not recorded. This pre-AE velocity loss generally requires approximately 0.4 to 1.0 mph of velocity loss in 20 to 30 ms. Therefore, the recorded maximum Delta V value of 6.1 mph is most likely 6.5 to 7.1 mph in reality (6.1 + 0.4 to 6.1 + 1.0). Assuming an average AE adjustment of 0.7 mph, the median AE-threshold-adjusted Delta V_{max} is 6.8 mph. A full time period trace of the average AE-adjusted

[14] Recall that the 1999 model year vehicle air bags were both deployed, but we now see that the recorded velocity change was only 6.1 mph, well below the Delta V deployment threshold. However, for the system on that vehicle, there are actually multiple valid firing criteria and an auxiliary sensor to detect the high impact experienced by the vehicle. The air bags were deployed by a criteria set other than the strict Delta V threshold.

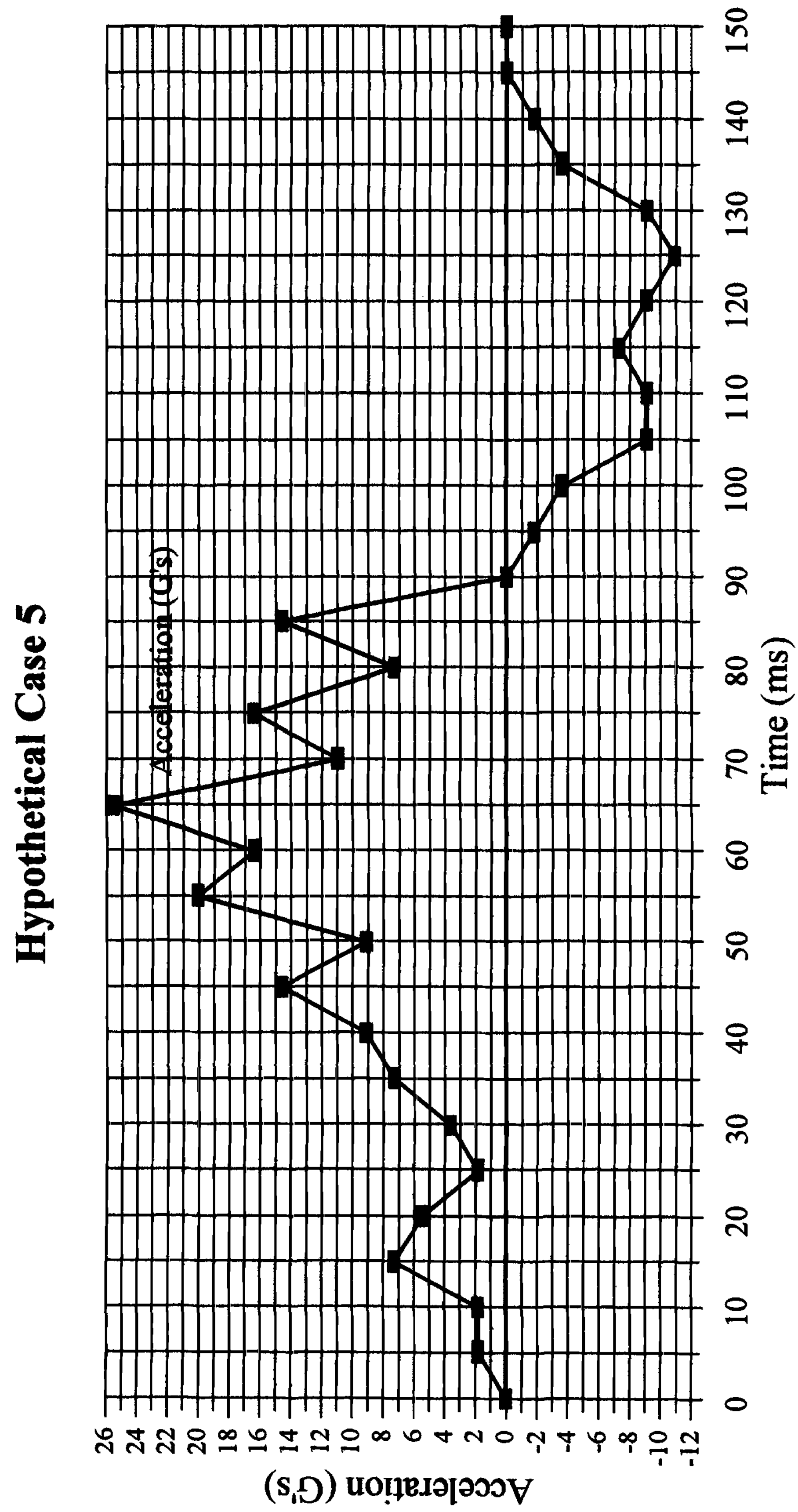


FIG. 6.30—Case 5 acceleration as derived from cumulative velocity change data in ECU EEPROM.

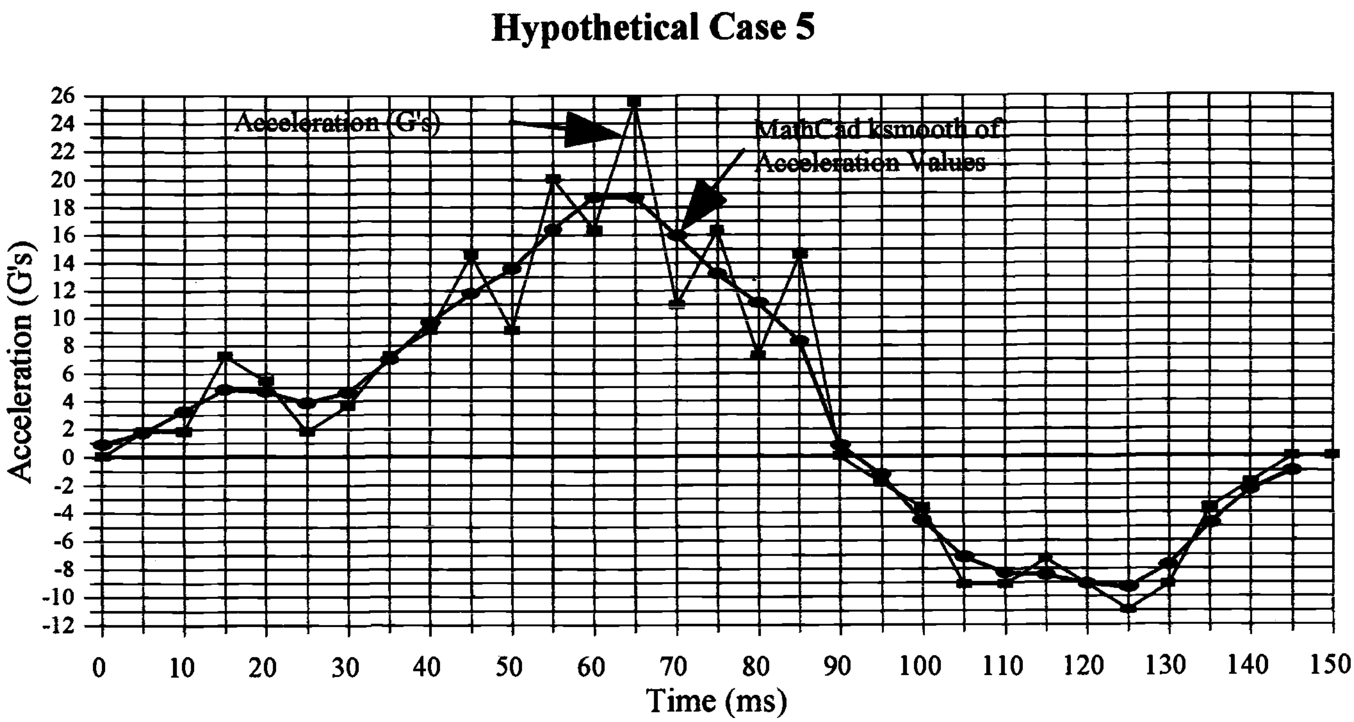


FIG. 6.31—Case 5 smoothed acceleration as derived as derived from cumulative velocity change data in ECU EEPROM.

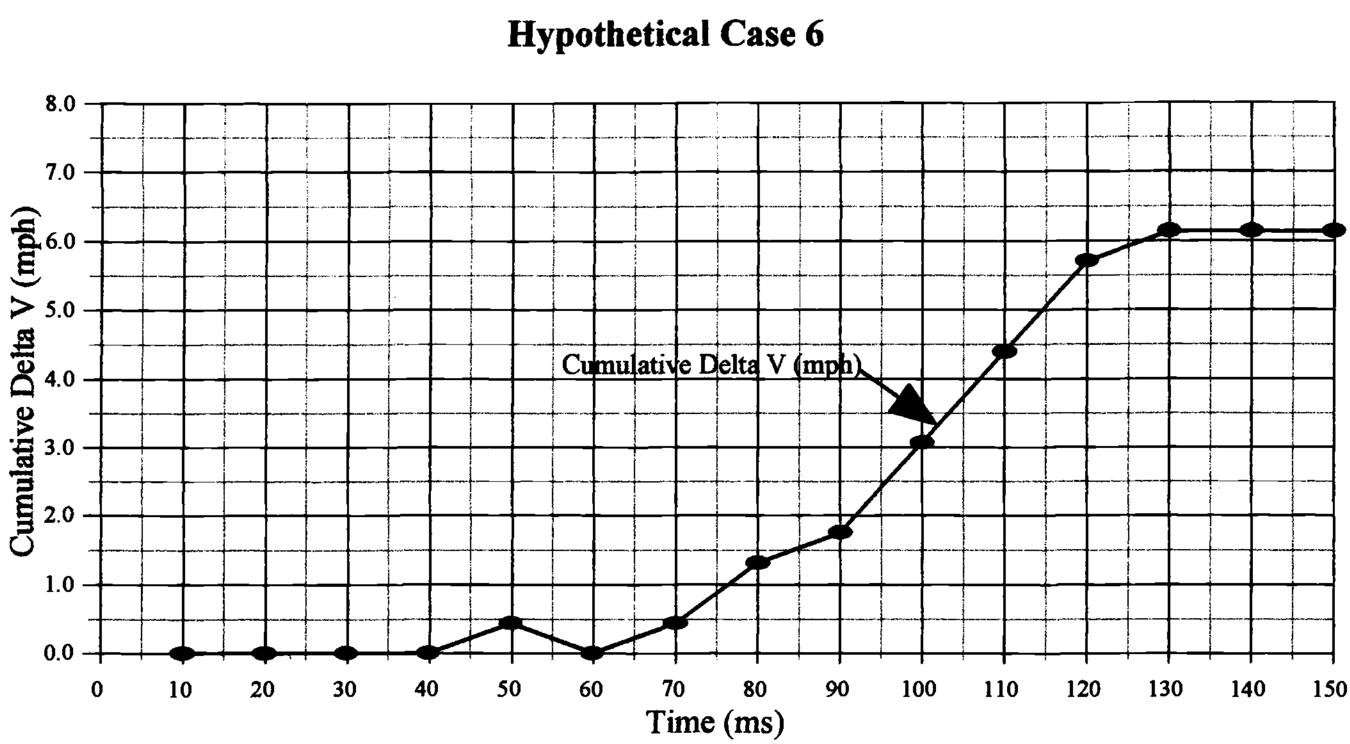


FIG. 6.32—Cumulative velocity change (loss) as directly interpreted from hex data.

Delta V is shown as superimposed over the original interpreted Delta V trace in Fig. 6.33 (the trace labeled Crash 1 + AE).

3. A second adjustment is necessary because the SDM's internal accelerometer is directionally sensitive. Thus, the recorded Delta V values may need to be geometrically corrected to give the true impact velocity along the Principal Direction of Force (PDOF).
   a) For example, if the PDOF is determined to be 15° from the longitudinal (X) axis of the vehicle, the following correction to the recorded Delta V data would be made:
   b) We take the average AE-threshold-adjusted maximum Delta V (6.8 mph) and use the geometric relationship shown in Fig. 6.34. From that geometry we know that:
   c) (AE-adjusted-max) = −X axis Delta V = (PDOF Delta V) × (cos (15°))
   d) PDOF Delta V = (−X axis Delta V)/cos (15°)
   e) cos (15°) = 0.966
   f) Thus, for our vehicle data, and an assumption of 15° PDOF, our final determination of impact velocity can vary as follows:
   g) $P_{AE\text{-average-adj-max}}$ = 6.8 mph/cos (15°) = 7.0 mph
   h) A full time period trace of the Geometric+AE-adjusted Delta V is also shown in Fig. 6.35 (the trace labeled Crash 1 + AE + PDOF).
4. We can now combine this double-adjusted Crash Delta V with the pre-crash data and obtain a very complete braking and velocity loss profile for the subject accident that also includes an indicator as to when the operator perceived the impending impact and started braking. This is accomplished as follows:
   a) Referring to Fig. 6.36, it was recorded that the vehicle was traveling at 30 mph at 2 s before impact, 21 mph at 1 s before impact, and during the impact we have determined that the vehicle lost 7.0 mph in the crash event (using the double-adjusted Delta V). We also know that it was sometime in the period from 2 to 1 s before impact when the operator applied the brake, but, because the system records its data only on even second boundaries, we cannot yet be more time-specific.
   b) The CDR pre-crash data graph, Fig. 6.36, shows a straight line deceleration of 9.0 mph in the period from 2 to 1 s before impact. This implies a deceleration rate of 9.0 mph/s, or 0.41 *G*.[15] However, 0.41 *G* is not indicative of an operator applying the brake in a constant hard manner when he/she realized there was a collision impending. Hard braking, on a typical road surface, should produce decelerations in the range of 0.6 to 0.8 *G*.
   c) To determine more accurately probable pre-impact braking pattern,[16] we must see if there is a rationale for a more probable hard-braking deceleration value.
   d) We know that the subject vehicle was traveling 21 mph approximately 1 s before impact and 7.0 mph (the double-adjusted Delta V) at impact, approximately 1 s

[15] 1 *G* 32.2 ft/s/s 21.95 mph/s.
[16] And to add more resolution to the CDR parameter graph.

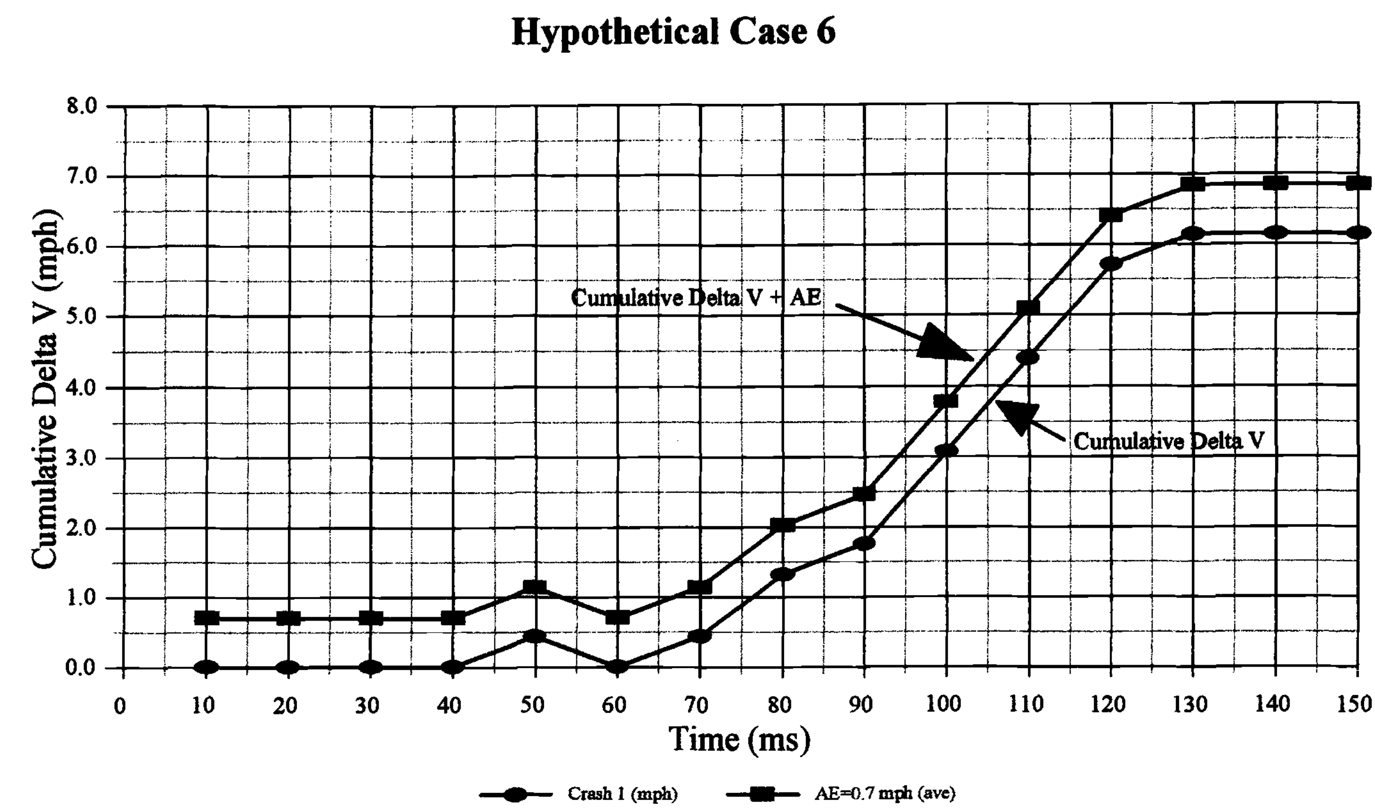


FIG. 6.33—Cumulative velocity change (from hex data) after adjustment for bias threshold.

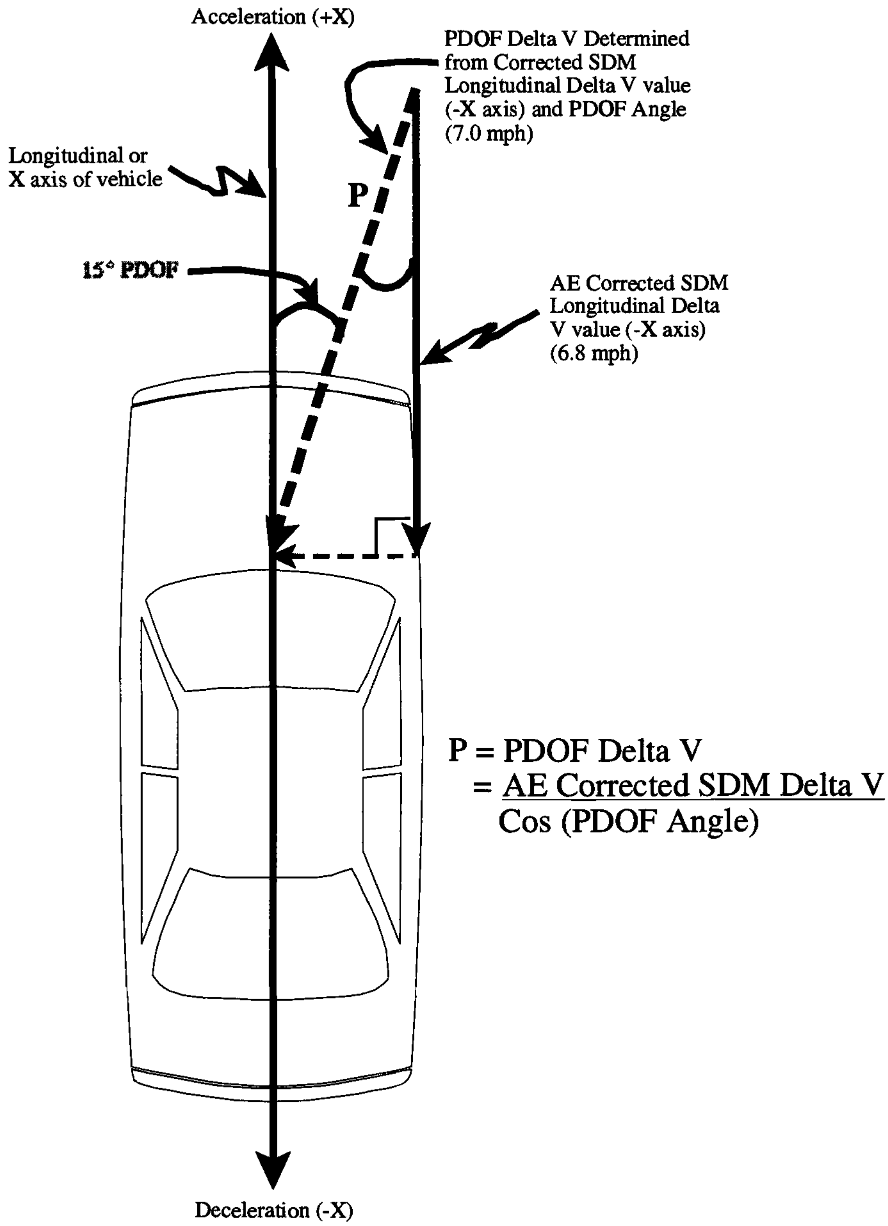


FIG. 6.34—Diagram of geometric adjustment to determining true PDOF velocity from ECU recorded cumulative velocity change.

later. Allowing a full 1 s for the time between −1 s and impact (0 s), we can imply a deceleration rate of 14.0 mph/s = 20.5 ft/s^2, or approximately 0.64 *G*.[17]

e) Knowing that the deceleration from −1 s to 0 s was 0.64 *G*, and now assuming a reasonably hard and constant brake application by an operator viewing an impending crash, we can assume that there was also a 0.64 *G* deceleration in the period from 2 to 1 s before impact. We also know that the vehicle lost 9 mph in that period. We can now determine approximately what time before impact the operator applied the brake. This is done as follows:
   i. Known: 9 mph velocity loss (13.2 ft/s), at assumed 0.64 *G* deceleration rate (20.5 ft/s^2).
   ii. Determine: $t_{\text{braking}\,(-2\text{ to }-1)}$ (time for which brake must be applied in the period from 2 to 1 s before impact).
   iii. $v = at$, transposing $t = v/a$.
   iv. $t_{\text{braking}\,(-2\text{ to }-1)} = 13.2$ ft/s/ 20.5 ft/s^2 = 0.64 s.

f) Therefore, assuming that the vehicle maintained its velocity at 30 mph from −2 s to the start of braking, and that the operator applied the brake reasonably uniformly, the brake was applied for a total of approxi-

[17] This is a high value, and near the practical maximum for a land vehicle on a typical road surface. We have allowed a full 1 s for the period from −1 s to 0 s (impact). If that time were made significantly shorter, the deceleration *G* value would rise to a value exceeding the practical maximum for a land vehicle on a typical road surface.

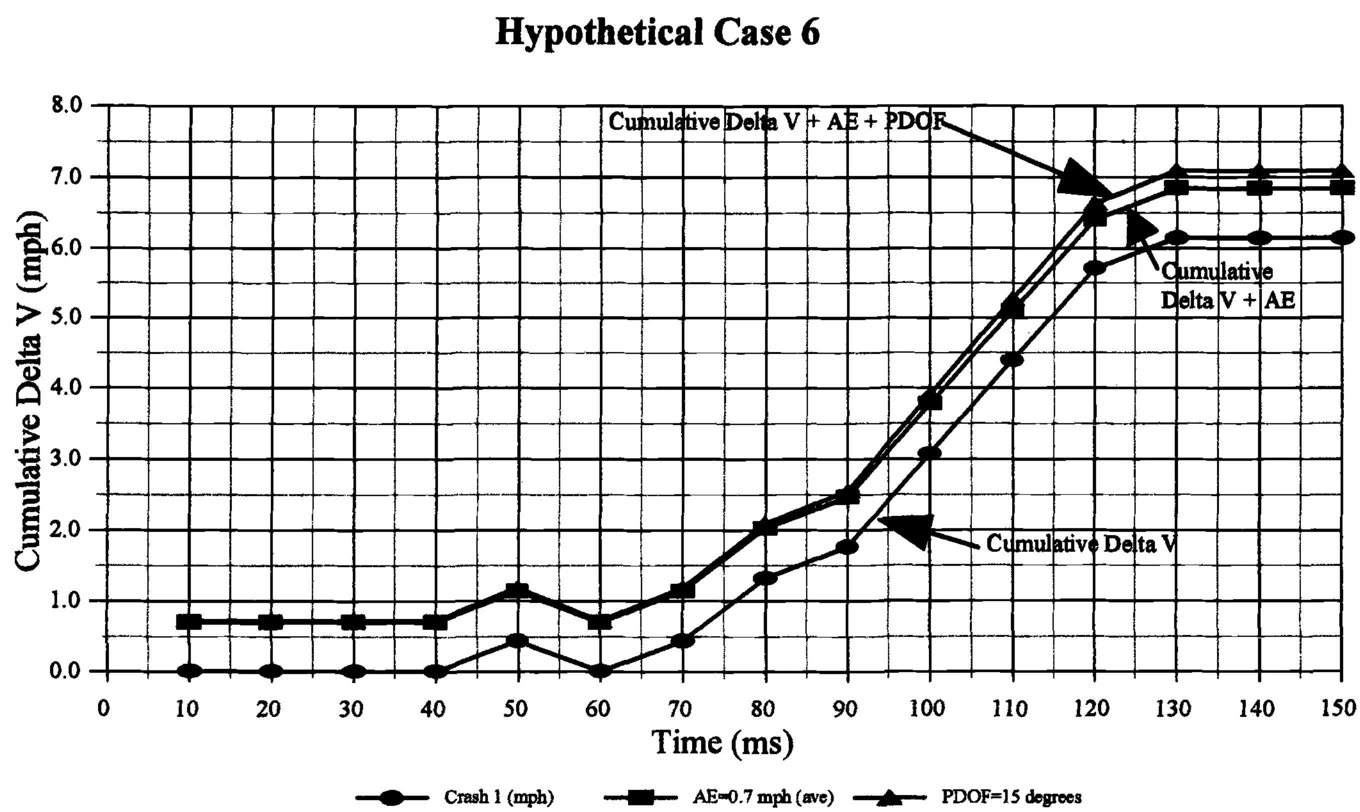


FIG. 6.35—PDOF corrected cumulative velocity change (Delta V).

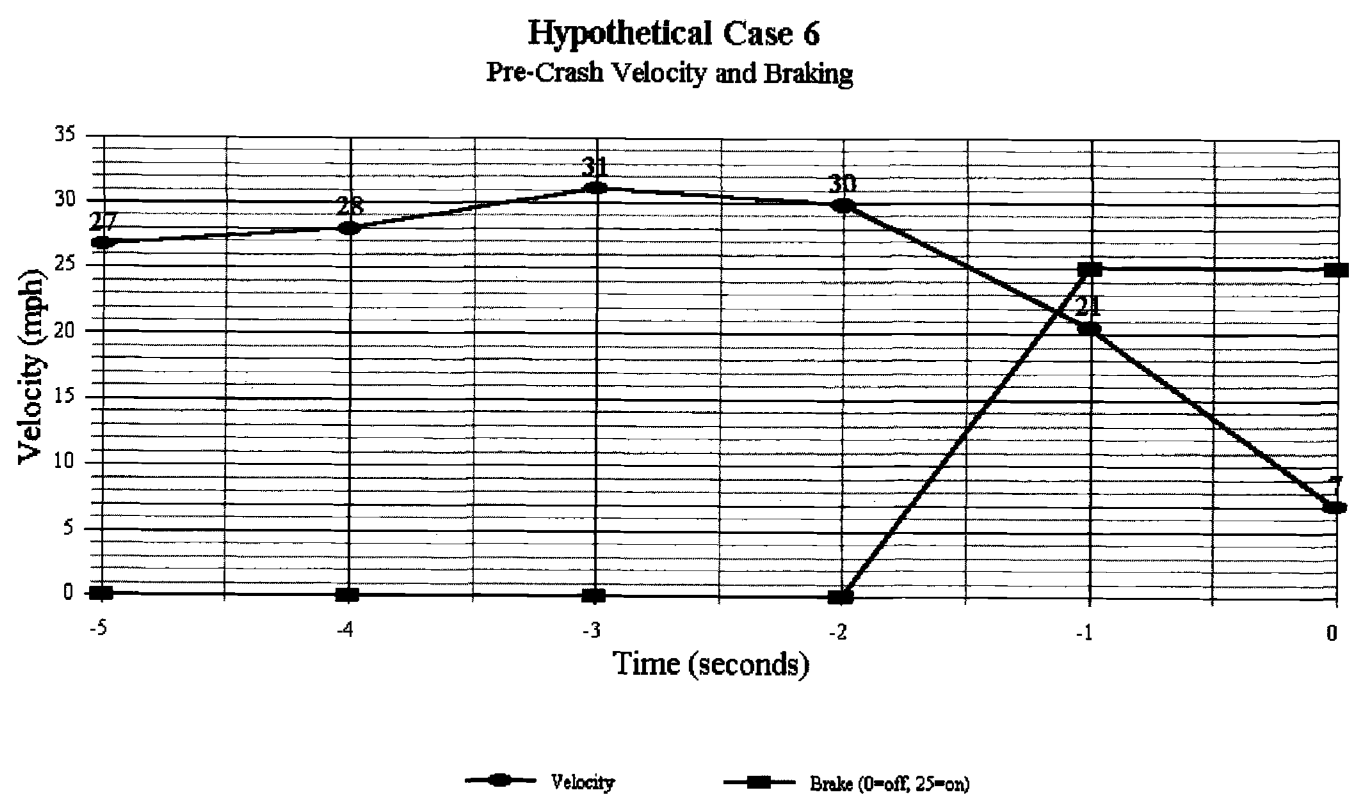


FIG. 6.36—Braking versus speed versus time profile taken directly from the Vetronix CDR printout for a 1999 domestic model year vehicle (Fig. 3.24). Note that brake application occurred sometime between 2 s and 1 s before impact, causing a velocity reduction of 9 mph (30 to 21 mph). Note: brake application is shown as a value of 25.

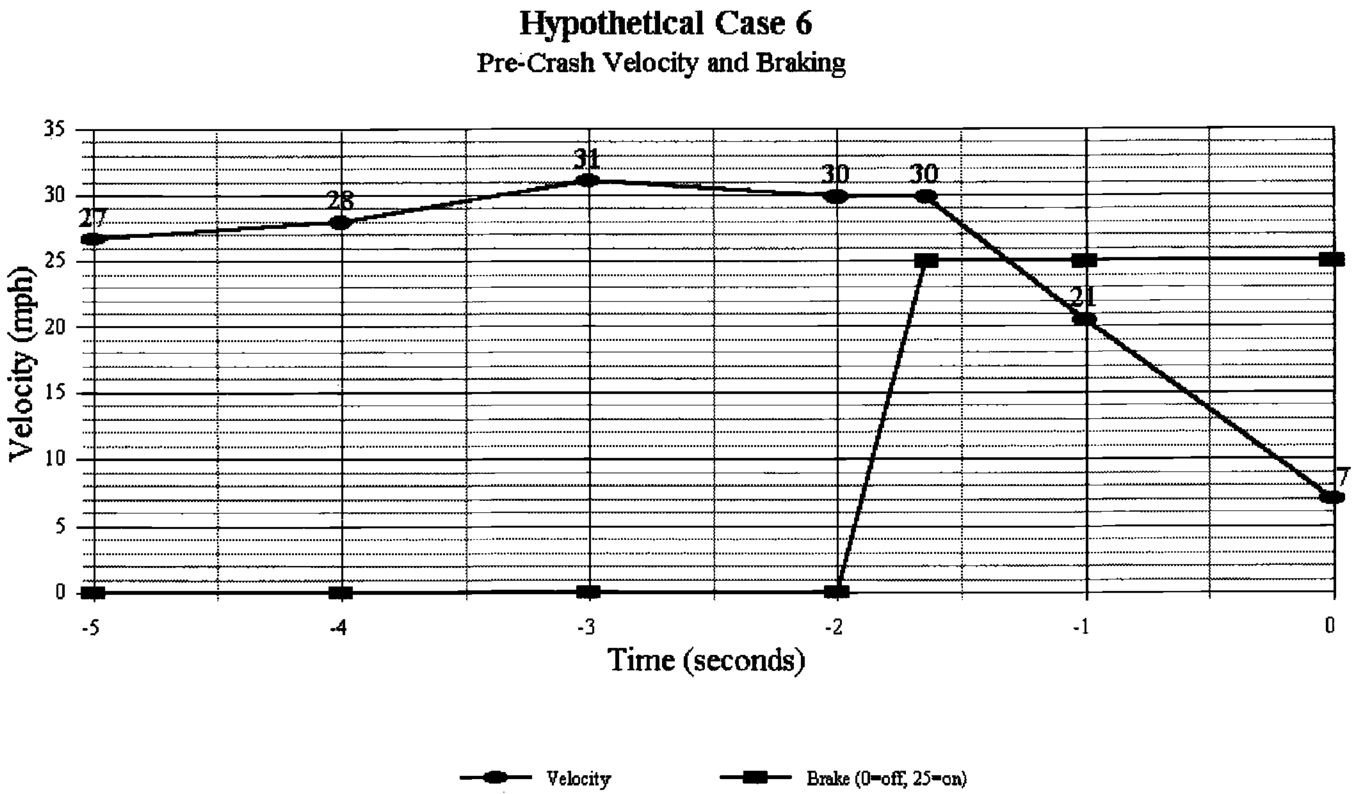


FIG. 6.37—Braking versus speed versus a time profile as adjusted for most probable operator actions.

mately 1.64 s before impact, providing a velocity loss of 23.0 mph at 0.64 *G*. This revised braking versus time pattern is shown graphically in Fig. 6.37. Note that, because the CDR records pre-impact data only on even second intervals, the revised brake apply timing as we have just calculated produces an identical CDR data record

and parameter graph as the original CDR data record shown in Fig. 3.24.

g) Again using those assumptions, we can now calculate the distance the vehicle traveled, with brake applied, before impact. Summarizing the facts we have determined:
Velocity before braking = 30 mph (44.0 ft/s)
Velocity at impact = 7.0 mph (10.3 ft/s)
Average velocity during braking period = (30 + 7.0)/2 = 18.5 mph = ⟨27.1 ft/s⟩
Time of braking period (before impact) = 1.64 s
We can calculate the distance traveled during braking as: $\langle v \rangle\, t$
$\langle v \rangle\, t$ = ⟨27.1 ft/s⟩(1.64 s) = 44.4 ft

h) This revised and more realistic profile of pre-crash time, distance, and brake-apply force can assist experts in Biomechanics and Human Factors to estimate the point at which the operator perceived the accident situation.

6.10 CASE ANALYSIS SUMMARY

This chapter provided case example crash data analyses for six different system types that have potential post-crash data content. For each of those cases, we walked through a step-by-step analysis and showed how our results were derived. Additional to crash velocity and timing data, we saw how occupancy, seat belt usage, and prior history can be obtained from certain ECUs. These were then combined to extend mere data translations to provide a second, more sophisticated, level of crash anatomy analysis.

The purpose of these exercises was to give the reader a set of methodologies that he/she can employ or adapt to another specific system of his/her interest.

Lastly, the case examples showed, both directly and indirectly, how post-crash investigators can provide more quantitative data to investigators in associated sciences (medical, biomechanics, and human factors).

7

The Future of Vehicle Black Box Data Storage

7.1 FORECASTING ADVANCED ELECTRONICS APPLICATIONS IN VEHICLES AND COMPLEMENTARY EVENT DATA STORAGE CAPABILITIES

ELECTRONICS CONTENT IN AUTOMOBILES are forecasted to have an economic growth rate of 8 to 9% (Rajan 1999; Fry, undated, Detroit News on the Web 1999). This increasing electronics content will unquestionably bring fundamental changes to vehicle electrical systems and to vehicle electronics function.

Passenger vehicle electrical systems moved from the original 6-V systems of the 1930s and 1940s to 12-V systems in the mid-1950s. This was done to accommodate increased electrical energy requirements and to reduce the weight and cost of increasingly complex vehicle wiring. In the early 2000s, passenger vehicle electrical systems will migrate to 36 V,[1] and some currently belt-driven components may be combined with gear-driven components, such as a combined alternator-starter-flywheel (CarToday.com 1999; McAlinden et al. 2000).

With respect to electronics function, we will see advanced vehicle electronics combinations that will optimize performance, protection, security, and safety. In many applications, sensor data will be shared (via the vehicle data network), and, in many applications, ECU-processed data will be shared (also via the vehicle network). The beginnings of this concept are seen in current vehicles where vehicle speed and chassis acceleration are shared by multiple systems. As shared sensors become more sophisticated, we will unquestionably see more refined electronic controls using advanced and innovative in-vehicle sensors.

Given this trend, it is easy to predict that increasing data storage capability included with those electronics components will only increase post-crash event data availability. This is mostly because such capability is essentially already built into the microprocessors and controllers that will be used to implement these features and systems. The advent of such capability has already been noted in the general press (Van Vorhis 1999; Wald 1999).

Event data capability may be independent, or it may be subsumed into the data content of (crash) event data recorders (EDRs) that may exist in the future. That is, true EDRs will actually gather pertinent pre-crash and post-crash information into one device (EEPROM/flash memory) for later recovery. One early example of this is found on selected 1998 to 2000 model year General Motors vehicles (as discussed in Section 7.2 below). Thus, if we examine advanced trends and strategies in powertrain controls, driver information, body/chassis controls, and safety systems we can forecast the potential availability of crash event data in future vehicles.

[1] The reader should note that vehicle battery charging and operating systems typically run at voltages greater than the above-stated 6, 12, and 36 V. Thus, 6 V systems typically ran at 7 V, 12 V systems typically run at 14 V, and 36 V systems will typically run at 3 × 12 V system voltage (14 V), or 42 volts. Thus, the reader may read about "42 V" systems that actually will use 36 V batteries.

7.2 GOVERNMENT AND INDUSTRY ACTIVITIES CONCERNING GROUND VEHICLE EVENT DATA RECORDERS

There is already an established panel examining event data recorders in ground vehicles. The NTSB and NHTSA have convened an Event Data Recorder (EDR) Working Group, consisting of a panel of government and industry officials appointed by the Motor Vehicle Safety Research Advisory Committee's (MVSRAC) Crashworthiness Subcommittee. Meetings of the group are held at the National Highway Traffic Safety Administration's (NHTSA) headquarters in Washington, D.C. The charter of the group is derived from an NTSB recommendation that NHTSA "Develop and implement, in conjunction with the domestic and international manufacturers, a plan to gather better information on crash pulses and other crash parameters in actual crashes, utilizing current or augmented sensing and recording devices" (Ferlis 1998).

The group states its charter as:

1. Understand the status of EDR technology.
2. Understand the needs for crash data.
3. Review privacy issues.
4. Develop the working group.

Four meetings of this group are documented:

- EDRmtg1_981002
- EDRmtg2_990217
- EDRmtg3_990609
- EDRmtg4_991006

Documentation of these meetings may be downloaded by examining the dockets located at http://dms.dot.gov/search/, Docket 5218 (Acrobat reader (*.pdf) format) (Owings 1998, 1999a, 1999b). No future meetings are planned at this time (Hinch 2000). In the collected meeting minutes of this group one can view presentations from both government and industry representatives, with specific inputs from several manufacturers. Most notable from the minutes is a description of crash data retrieval capabilities in advanced General Motors vehicles (proprietary at the time of the meetings), the formats and interfaces for which have now been licensed to scanner manufacturer Vetronix, who is currently marketing a crash data retrieval system (CDR) to display these data (Chidester 1999).[2] Examples using the Vetronix CDR data are also shown in Chapters 3 and 6.

7.3 ADVANCED OCCUPANT SENSING, COLLISION DETECTION, AND SAFETY PROTECTION SYSTEMS

Auto manufacturers and regulators are ever cognizant to consumer feedback and are continuously searching for ways to improve vehicles with respect to occupant comfort, safety, and crash survivability. Since vehicle crashes seem to be inevitable and foreseeable, this objective includes both conceptual and practical ways to improve upon current systems and can be summarized in the nine segment Haddon Matrix (Haddon 1972).[3] The Haddon Matrix divides a crash event into three phases (pre-crash, crash, post-crash) and looks at the human, vehicle, and environmental considerations of each phase. An illustrative Haddon Matrix is shown in Table 7.1.

More sophisticated systems that further assist in injury prevention, injury limits, and/or crash prevention are generally called *smart systems* and incremental advancement levels are called *generations*. Thus, we can currently find such terms as *smart third generation air bag system* in the advertising literature. Unfortunately, there is no standard industry measure for *smart* or *generation*.

As one practical example, first generation air bag systems generally used distributed electromechanical discriminating sensors, and second generation air bag systems generally use integrated solid state accelerometer discriminating sensors. Third generation air bag systems will incorporate some sort of occupant sensing and/or air bag deployment power modulation, dependent on occupant sensing. However, crossovers and exceptions abound in past and current systems.[4]

Table 7.2, Example of SRS Deployment Decision Matrix—Generation 3+ Systems, provides an illustration of the decision tree process that is starting to appear in contemporary passive restraint smart systems.

Listed below is a compilation of expected features, sensors, and component advances, many of which will find their way into fourth, fifth, and sixth generation safety systems. From this compilation, and the SRS ECU decision tree process (using other-vehicle sensor parameters) incorporated into the SRS decision tree, one can see how it will be a small step to save many automotive crash event data points into EEPROM/flash memory. Thus, driven by safety enhancements, future automotive black box crash event data should start to approach the scope of data in current aircraft DFDRs (Appendix E).

7.3.1 Occupant Sensing

Newer generation air bags will use sensors to monitor vehicle speed, position of the driver and/or passengers, and the individual weight of each occupant, thereby allowing the SRS ECU to make decisions that will adjust the deployment force of the air bags/pretensioners so that the combination is strong enough to protect the occupant but not cause injury.

One type of occupant sensor will detect an occupant's weight and proximity to the air bag when seated in the vehicle. It will do this using strain gage-based force sensors located within or beneath the seat. Other sensors will detect whether the occupant's head is in the deployment path (throw distance) of the air bag. For instance, if the sensors detect a sleeping occupant, with his/her head leaning to one side, the side air bag can be deactivated to prevent rotated head or neck injuries caused by air bag deployment.

Seat position will be determined by sensing where the movable seat track is with respect to the stationary (floor) track, and, thus, where the occupant is positioned relative to the air bag deployment window. Other sensors will detect the

[2] The Vetronix crash data retrieval scanner (CDR) consists of a laptop computer interface to the OBD-II data port and has been programmed to access the crash-event-triggered data saved in certain GM SDMs. These data include engine RPM, cumulative Delta V, seat belt status, brake switch status, time from algorithm enable to deployment, and MIL status. Some GM models also provide brake, engine RPM, throttle %, and vehicle speed for five one-second intervals before impact algorithm enable. The reader should note that the CDR may not report all the data in the SDM EEPROM.

[3] William Haddon, Jr. was the first head of NHTSA.

[4] Exceptions include certain first generation systems that used accelerometers over 15 years ago, and certain systems that incorporated modulated deployment decisions, based on seat belt usage, over 10 years ago.

TABLE 7.1—Haddon Matrix

Phase \ Consideration	Human	Vehicle	Environment
Pre-crash	Occupant Position Occupant Belt Use Occupant Seat Loading	Throttle % Vehicle Speed ABS Status Other Controls	Visibility Traffic Road Surface
Crash	Thoracic Stress Head Stress Pelvic Stress Femural Stress	Measured Gs Computed VCrash Pulse Timing Pretensioner Deployment Timing Air Bag Deploy Timing	Geographic Location
Post Crash	Time Until Assistance	Collision Safeguards System Shutdown (anti-fire) Lock Systems Open (egress)	Emergency Notification (via auto-GPS/cell phone)

TABLE 7.2—Example of SRS Deployment Decision Matrix Generation 3+ Systems, RF Passenger Position, Longitudinal System Only

Deployment Zone / Sensor Detected Condition	Occupant Type	Occupant Position	Acceleration Estimate $\Delta V/t$	Occupant Belted	Potential Firing Decision
Occupant Type × Position × Delta V/t × Seat Belt Status	Adult, Large	FAR	High	Yes	BT, FA1
				No	FA1
			Low	Yes	BT, FA3
				No	FA2
		NEAR	High	Yes	BT, FA2
				No	FA2
			Low	Yes	BT, FA3
				No	FA2
	Adult, Small or Large Child	FAR	High	Yes	BT, FA1
				No	FA1
			Low	Yes	BT, FA2
				No	FA2
		NEAR	High	Yes	BT, FA2
				No	FA2
			Low	Yes	BT, FA3
				No	FA3
	Child Seat		Any	Yes	TBD
				No	NO

SRS ECU Deploy Codes	Belt Tensioner	BT	
	Front Air Bag P1	FA1	Highest Power
	Front Air Bag P2	FA2	Medium Power
	Front Air Bag P3	FA3	Lowest Power
	Right Side Air Bag	SA	

presence and orientation of a child seat in an air bag-vulnerable position.

Occupant and/or object sensing in various seat positions may also be accomplished by infrared (IR) or ultrasonic detectors (with internal microwave type sensors ruled out because of potential interference with medical appliances such as pacemakers).

From these sensor data, the seat position input and the occupant's weight distribution (center of gravity in the seat), and the occupant's type and position with respect to the air bag, can be determined accurately. Once this is determined, occupant positional position zones can be identified, each having separate modulated firing rules implemented by the SRS ECU microprocessor program logic.

If we conceptualize these conditions in a decision tree, we can envision the possible SRS ECU deployment logic for the right front passenger position as shown in Table 7.2, Example of SRS Deployment Decision Matrix—Generation 3+ Systems.

7.3.2 Modulated Air Bag Inflation

When a system has two separate inflators that can be activated separately or together, the air bag deployment aggressivity can be modulated depending on vehicle speed, seat belt usage, seat position, etc. In relatively low speed impacts, the inflators can be activated one after the other for slower inflation. At higher speeds, both inflators are activated simultaneously for quicker inflation and maximum effective protection.

New air bag envelope designs will allow tailored inflation profiles for air bags. One method of accomplishing this employs delivery of inflation deploying gas through narrow radial chambers, which then fill an outer chamber closer to the occupant. This process, in effect, produces a two stage inflation of the bag.

Both Systems (1) and (2) effectively reduce raw air bag power, compared to Generation 1 simple air bags.

Seat belt usage can be incorporated as one factor to adjust Delta V deployment thresholds, thus inhibiting late air bag deployments at low Delta V (where the risk is greatest) when seat belts are worn.

Seat belt usage can be used to control the seat belt pretensioners, switching them off if the belts are not used or in very low speed accidents.

Ultrasonic-based occupant spatial position sensing can be used to modulate or inhibit air bag deployment for out of position (OOP) occupants.

TABLE 7.3—EDR parameter objectives as compiled from passenger, trucking and NTSB/NHTSA information.

Current System or Projected Source / Desired EDR Parameter	EDR Specification			Chassis Parameters					Body Parameters		
	Save Trig	Samp Period	Samp Rate	PCM, VCM	ABS TCS	Trns ECU	Susp ECU	Steer ECU	SRS ECU	Body ECU	T ECU
ABS, Status @ Event	DTC	1	1		X						
ABS, Speed, Wheels	DTC	1			X						
ABS, Status @ Event	crash	1	1		X						
ABS, Accel Vertical (Z axis)	contn	1	1		X						
ABS, Accel, Lateral (Y axis)	contn	1	1		X						
ABS, DTCs	DTC	1	1		X						
ABS, Accel, Longitudinal (X axis)	contn	1	1		X						
Body, Comfort & Entertainment	contn	1	1							X	
Body, VIN	1	1	1								
Body, Non Registered ECUs	1	1	1								
Body, # Occupants	crash	1	1						X		
Body, Location, GPS	crash	1	1								
Body, Electronic Compass Heading	crash	1	1								
Body, Date, Time	crash	1	1						X		
Body, Automatic Collision Notfication, ACN	crash	1	1								
Body EDU, Door Lock State	crash	1	1							X	
Brakes, Air Pump Status (Diesel, Air Brakes)	contn	1	1								
EDR, Speed, Max, Trip	contn	1	1								
EDR, Trip, Time	contn	1	1								
PCM, RPM, Max, Trip	contn	1	1	X							
PCM, RPM, IDle, Time Max, Trip	contn	1	1	X							
PCM, Power Take Off, Usag,e Trip	contn	1	1	X							

TABLE 7.3—*(continued)*.

Desired EDR Parameter \ Current System or Projected Source	EDR Specification			Chassis Parameters					Body Parameters		
	Save Trig	Samp Period	Samp Rate	PCM, VCM	ABS TCS	Trns ECU	Susp ECU	Steer ECU	SRS ECU	Body ECU	T ECU
PCM, Speed, Vehicle,	contn	contn	1 sec	X							
PCM, Elect, Voltage, Battery	crash	1	1	X							
PCM, Elect, Voltage, Alternator	crash	1	1	X							
PCM/VCM, CruiseControl, ON/OFF	crash	1	1	X							
PCM/VCM, DTCs, Emissions, w/Freeze-Frame	DTC	1	1	X							
PCM, Odometer	crash	1	1	X							
PCM, Speed, Vehicle,	crash	300 ms	5 ms						X		
SRS, Accel, Lateral (Y axis)	crash	1	1						X		
SRS, Accel, Longitudinal (X axis)	crash										
SRS, Child seat Present in RF	contn	1	1						X		
SRS, Child seat Present in RF	crash	1	1						X		
SRS, Algorithm Enable (AE) to Deploy	crash	1	1						X		
SRS, DTCS	contn	1	1						X		
SRS, RF Passenger Disable Switch	crash	1	1						X		
SRS MIL status	crash	1	1						X		
SRS, Seat Belt Status	crash	1	1						X		
SRS, Seat Position	crash	1	1						X		
Steered Wheels, Relative Directional Angle, Deg	contn	contn	1 s					X			
Steering, DTCs	DTC	1	1					X			
Steering Wheel, Rate, deg/sec	crash	1	1					X			
Steering Wheel, Rate, deg/sec	contn	contn	1 s					X			
TCS, Traction Coeff	DTC	1	1		X						
TCS, Status	contn	1	1		X						
Transm, PRNDL position	crash	1	1			X					
Transm ECU, Status	contn	1	1			X					
Transmission, DTCs	DTC	1	1			X					

Seat-track and seated-weight sensors can be used to determine position (forward-rearward) and type of occupant (child seat, small adult, large adult) in order to inhibit or modulate air bag deployment.

Combinations of the above systems will certainly be used, and some are seen in 2000 to 2001 vehicles.

7.3.3 Collision Avoidance Sensing

One approach to mitigate injuries to occupants in collisions is to attempt to avoid collisions themselves. To that end, certain obstacle-proximity detection devices are being developed that detect impending collision targets. These devices function using low power radar-like microwave transmitters and driver proximity alert indicators. This concept can be easily extended to include indicators such as those used in aircraft stall warnings to alert a driver of an impending collision danger. First generation systems of this type are currently employed in Canadian fleet vehicles for backup sense and warning.[5]

[5] Sense Technologies Inc, Guardian Backup System, 23 Feb. 2000.

7.4 WISH LIST PARAMETERS IN FUTURE VEHICLE CRASH EVENT DATA RECORDERS

Various reviews of vehicle EDR capabilities have produced increasingly sophisticated inter-agency and inter-company objectives for desired EDR parameters. These will allow us to learn more about current accidents so that the occupant outcomes in future accidents can be optimized. A compilation of these parameters is listed in Table 7.3, Desired EDR Parameters. Some parameters are actually saved in vehicle systems now, some will be saved in the near term, and some will follow in the future. For those parameters saved now or in the near term, only a subset may actually be accessible by investigators, and then only to those with special knowledge.

Lastly, just as with aircraft CVR and DFDR data, the inexorable progress of time and technology will serve to make the set of saved data parameters increasingly more complete and more useful, and so the compilation presented here will probably be considered only a primer for future investigators of electronically saved accident data.

APPENDIX A

Glossary of Terms and Conversion Factors Used in Vehicle Data Systems[1]

Name/Acronym	Description	Function
⟨a⟩	Average acceleration ⟨a⟩	Notation used to denote the average value of acceleration over a specific time segment or period. Also see $a_{average}$.
μS or US	microseconds	1/1 000 000 second = 10^{-6}. Used as a measure of time when describing SRS timing events, usually with multiplier.
2s Complement Signed Numeric Byte		2s Complement Signed Numeric Byte, where the numeric value of the lower 7 bits (Bits 0 to 6) represents a value whose sign depends on the MSB (most significant bit, Bit 7). If the MSB is "1" the value is negative, and if the MSB is "0" the value is positive. Similarly to 4, the decimal interpreted value represents an engineering unit, depending upon a value resolution specification (e.g., each count = 0.5 mph).
4WAL	Four Wheel Anti Lock	Describes 4-wheel (versus rear-wheel-only) antilock braking system
5/30 Rule	5 in./30 ms timing rule	The 5-30 rule was established on the basis of a 30 mph frontal barrier collision, wherein an unrestrained driver will have moved 5 in. forward from his or her seated position at the instant of the crash.
A/D	Analog-to digital	Used to describe an electronic function that converts an analog voltage input (usually from a sensor) into a digital value that can be used in computer calculations (also see Scale Factor and Engineering Units).
$a_{average}$	Average acceleration	Notation used to denote the average value of acceleration over a specific time segment or period. Also see ⟨a⟩.
ABRS	Air Bag Restraint System	Generic name of SRS that provides an air pillow/cushion restraint to prevent contact with the steering wheel and other objects in the car. Also see SRS, ACRS, etc.
ABS	Antilock Braking System	Electronically modulated braking control system that prevents individual wheel lockup on road surfaces with varying coefficients of friction.
AC	Alternating Current	Electrical power source embodying periodically inverting voltage polarities. As distinguished from DC, direct current that defines a power supply of constant polarity.
Acceleration		A term used to denote the time rate of change of velocity.
Accelerometer	Solid state device, usually contained within the SRS ECU.	Accelerometers produce a continuous voltage output proportional to the deceleration pulse magnitude. The time pattern of that output is called the deceleration pulse (waveform, or crash signature). The cumulative time integral of the deceleration pulse is the cumulative velocity change (deceleration) of the crash vehicle. The MPUs within the ECU compare the subject crash deceleration pulse (signature) with prestored crash test pulse patterns (known threshold signatures) to determine if the air bags should be fired.
ACRS	Air Cushion Restraint System	Generic name of SRS that provides an air pillow/cushion restraint to prevent contact with the steering wheel and other objects in the car. Also see SRS, SIR, ABRS.
Active Filter		An electronic filter that combines active circuit devices, usually op amps, with resistors and capacitors. Typically, active filters more closely match ideal filters than passive filters do.
ADC	Analog-to-digital converter	An electronic circuit that produces a digital output directly proportional to an analog signal input. Also see A/D converter.
Algorithm		A set of rules with a finite number of steps for solving a problem. In the context of this book, a computational procedure used to determine whether or not to fire the air bag(s) and/or seatbelt pretensioners in newer model cars.
Alias Frequency		A false lower-frequency component that appears in analog data that is reconstructed from original data digitized at an insufficient sampling rate. Also see Nyquist Sampling theorem.
Anti-Alias Filter		A filter that attenuates noise and high-frequency components of an analog signal prior to its sampling and conversion into a digital value, to prevent aliasing (false signal content due to undersampling of high frequency components of the source data).

[1]Portions of this glossary may be similar to, or reprinted from, Chapter 2, "Air Bag System Analysis," *Forensic Accident Investigation: Motor Vehicles, Vol. 2*, with the express permission of the publisher, Matthew Bender & Co, Inc., a part of LEXIS-NEXIS.

Name/Acronym	Description	Function
a_{peak}	Acceleration, peak value.	Maximum instantaneous value of acceleration during a particular event. Also see accelerometer, T_{pulse} and ΔV.
ASCII Encoded Byte		ASCII Encoded Byte, where the value of the byte indicates an ASCII character. ASCII encoded bytes are the type of bytes sent by computers via parallel ports to printers to print text documents.
ASDM	Air Bag System Diagnostic Module	Electronic controller that continually checks the functional readiness of the air bag system. A manufacturer specific name for the generic "SRS ECU."
Asynchronous		An action that takes place at an arbitrary time, without synchronization to a reference timer or clock.
a_{thresh}	Acceleration Threshold	Minimum value at which sensors or an algorithm responds. Usually stated as a function of Gs vs. base ms vs. waveshape (haversine or half-sine).
Attenuation		The difference in a signal=s voltage, current, or power after passing through a device or system, i.e., the signal loss from input to output ports.
Averaging		A mathematical smoothing the results of several measurements by adding them and dividing by the number of samples.
Balun		An antenna-balancing device that matches a balanced or symmetrical load (a dipole antenna) to an unbalanced load (a coaxial-cable feed line). Balun is derived from balanced-to-unbalanced.
Bandwidth (BW)		A range of frequencies over which a system works without materially degrading the original signal.
Binary Coded Decimal Byte		Binary Coded Decimal Byte, where each 8-bit byte is split into two 4-bit halves (called nibbles) and the numeric value of each nibble represents a decimal digit.
Bit Map		A set of values that specify information in a binary value. Used to specify colors or gray levels in an image, or to provide mask values in a DTC list.
Bit Mapped Without Mask Byte		Bit Mapped Without Mask (byte), where each bit of an eight-bit byte represents a predefined binary condition (e.g., on/off), dependent upon the position of that byte within the byte.
Bit Mapped With Mask Byte		Bit Mapped With Mask Byte, where each bit of an eight bit byte represents a binary condition (e.g., on/off), dependent upon the position of that byte within the byte, and the data byte is followed by a definition (mask) byte indicating which data bits of the information byte are valid.
BNC	Electrical Connector Type	A type of coaxial cable electrical connector using positive twist-lock bayonet attaching method. Useful where vibration-induced diskonnects might affect system integrity such as in aircraft, automotive, or shock-test environments.
BNC	Bounce (abbreviation)	Term used to describe diskontinuities in air bag sensor switch signal conductivity during closure period. Sometimes stated as BNC_{max}, which is the accumulated open time during which the sensor switch should have been (stayed) closed.
BOO	Brake ON OFF	See Stop Lamp Switch
Boost, Vacuum		Device to amplify operator brake pedal force input to the master cylinder. Uses engine vacuum to charge a vacuum servo or "booster diaphragm" directly in front of the master cylinder.
Boost, Hydraulic		Device to amplify operator brake pedal force input to the master cylinder. Uses motor pump to charge a hydraulic servo or "booster piston" directly in front of the master cylinder.
BPMV	Brake Pressure Modulator Valve	A valve tree assembly used to modulate brake wheel cylinder pressures and thus control individual wheel lockup on road surfaces with varying coefficients of friction.
bps	bits per second	Bit rate at which serial data are transferred. One character typically takes 10 bits (8 bits with the ASCII code, one start bit and one stop bit).
Brake Switch		Switch actuated by operator actuation of brake pedal. Can be hydraulic (i.e., on master cylinder circuit) or mechanical (i.e., on brake pedal swing arm). This switch is used to actuate or release related components such as ABS, TCC, CC, etc.
Brake Pads	Disk Brake Component	Friction apply components that are squeezed by caliper against the disk to provide stopping torque.

Name/Acronym	Description	Function
Brake Shoes	Drum Brake Component	Rectangular shaped friction apply surface on a nonrotating arced steel backing plate which is forced by the wheel cylinder(s) against the rotating brake drum to provide stopping torque.
Braking Coefficient		Ratio of baking force to vertical load.
Brushes and Slip-Ring	Rotary Connector at Steering Wheel. Spring-Tensioned Brushes (4) sliding on concentric commutators under steering wheel.	Component to electrically connect a rotating member to a stationary member. In the context of this book, a driver steering column component to electrically connect driver steering wheel air bag to its firing circuit and/or SRS ECU.
Byte		8 bits of binary data.
CAD	Computer Aided Design	Generic name of various design systems used to create engineering drawings. Can be considered the dual of various word processing programs used to create text documents.
CAE	Computer Aided Engineering	See CAD.
CAN	Controller Area Network	A network of computer controllers (microprocessors) that are constantly communicating with each other via a common serial data path.
Canister		A sealed device containing ignition capsule and gas generant. May have an inner filter.
Capacitor	Electrical Storage Device	Used to store electrical energy. In SRS systems, used to provide deployment energy in the event of a severance of battery cables in a crash, to deploy air bags and/or seat belt pretensioners.
Case		Metallic outer housing of an assembly or sensor, generally assumed to be grounded. Some systems generate diagnostic codes indicating the absence of case ground.
Checksum		A quantity added to the sum of a group of data values to make it come out even (00000000), or odd (11111111). Usually transmitted with the data to assist in error detection.
Clockspring	Rotary Connector at Steering Wheel. Helical multi-line spiral conductor contained in capsule under steering wheel.	Component to electrically connect driver steering wheel air bag to sensors and SRS ECU. Generally has superior conduction qualities when compared to sliprings and brushes.
CMOS	Complementary Metal Oxide Semiconductor	A semiconductor technology chosen for its low power consumption and good noise immunity. CMOS uses both N-channel and P-channel MOSFET devices. MOSFET devices operate by using a change in conductivity caused by the varying electrical field created by a control electrode (gate) insulated from its substrate by a silicon oxide.
Cold-Junction Compensation		An artificial reference level used in thermocouple conversion circuits.
Combination Valve		Composite of three valves used to: a. Hold-off front apply till rears are pressurized (called metering function). b. proportion rear hydraulic circuit. c. close switch (Brake MIL) to alert driver to pressure imbalance in brake circuit master-cylinder output.
Compensation Port		Port in Master Cylinder that allows brake circuit fluid flow to and from the reservoir, before any piston (pedal) pressure.
Connector Assurance Latch		A redundant lock on air bag system electrical connectors (or any other critical connector) to assure that the wiring harness connector will not simply unlatch from vehicle vibration, etc. Normally, this connector assurance latch must be removed first, in order to allow disassembly of the actual electrical harness connector. Also called secondary latch.
Connector	also: plug, pigtail	A device that electrically interconnects the main wiring assembly to other components and hardware.
Consult	SRS ECU Scanner	Tool for reading internal EEPROM stored codes and crash data.
Coolant	A chemical added to the gas generant to reduce the gas temperature.	Also, a chemical mixture used in engine heat management systems.
COP	Computer Operating Properly. Also: watchdog.	Circuit used to detect device runaway or stall, and used to provide a means for restoring correct operation or alerting an operator of malfunction.
Counter		In software, a memory location used to store a count of certain occurrences. In hardware, a set of latches which are used to save accumulated values. Typically used in clocking circuits such as a time of day counter.

Name/Acronym	Description	Function
CPU	Central Processing Unit	
Crash Datagram		Parameter map of acceleration and timing parameters recorded in crash event. Read out with special SRS ECU EEPROM Scanner.
Crash Sensor	Detector for high-level deceleration impulse resulting from vehicle collision. Also called Discriminating Sensor.	
Cross Assembler		A program that runs on one computer and generates instructions for another type of computer.
Crossover Channel		Hydraulic Channel used in fixed-caliper designs (pistons on both sides of rotor) to route fluid across the caliper.
Crosstalk		Inadvertent signal generated when one or more signals interfere with another signal. Usually classed as noise degradation.
Cushion	Inflated Envelope	Also called air cushion or air pillow, i.e., the "air bag."
Cycle		One complete sequence of regular-periodic actions, i.e., an ignition on-off cycle or a wheel oscillation bounce or an electrical waveform period.
Cycle Code		Error Code saved in memory during ignition cycle in which it occurred. Usually disables the system function for that cycle only.
D/A	Digital-to-analog	An electronic circuit that produces an analog output directly proportional to a digital value input.
DAC	Digital-to-analog converter	An electronic circuit that produces an analog output directly proportional to a digital value input.
Damping		A means to dissipate energy in vibrating or oscillatory systems. Also refers to the amount of overshoot allowed, or seen, in system responses.
Data Acquisition (DAQ)		Generally, a digital system to gather and store information from external sources such as sensors, transducers, etc. Data are usually stored in computer media.
DC–DC Converter	Electrical circuit that converts input DC voltage to a higher DC output voltage.	In the context of this book, a circuit section used to create an elevated storage voltage on an energy storage capacitor for the emergency deploy reserve.
DC	Direct Current	Electrical power source embodying constant voltage polarities. As distinguished from AC, this defines a power supply embodying periodically inverting voltage polarities.
Delta V	Also shown as ΔV.	The change in linear velocity during a specific time period. Note that a ΔV of 30 mph over a period of 200 ms vs a period of 50 ms produces markedly different waveforms and peak accelerations, a_{peak}.
DERM	Diagnostic Energy Reserve Module	G.M. Generation 1 SRS diagnostic and energy reserve module. Continually checks the functional readiness of the air bag system and saves DTCs and certain crash event timing data.
Diagnostic Module		A module containing electronic circuits that provides one or more of the following: system monitoring, system readiness, readiness indicator, and warning indicator prove out features.
Diffuser		A device on most inflation canisters to filter and distribute the inflation gas generant before it fills the air bag.
Digital-to-Analog Conversion		An electronic circuit that produces an analog output directly proportional to a digital value input.
DIP	Dual In-line Package	Describes the pin layout on an integrated circuit component (MPU, Clock, EEPROM, etc.).
Direct Memory Access (DMA)		The direct transfer of information between a computer=s memory and a device while the computer=s CPU does something else.
Dither	Vibratory control of valve position.	Method of preventing hydraulic valve clog at any particular flow rate.
DLC	Data Link Connector	Generic term describing diagnostic scanner access port to a vehicle communication network.
DMM	Digital Multimeter	Electronic test meter, combining current, voltage, resistance, etc., measurement functions, which does not significantly load the measured circuit. Also called DVM. This not the same as a legacy analog volt meter which loads the measured circuit.
DOT Class B	Explosives Classification	Explosives that produce rapid combustion and gases.

Name/Acronym	Description	Function
DOT Class A	Explosives Classification	Explosives that detonate, maximum explosion hazard.
DOT Flammable Solid NOS		Any solid material other than an explosive which can, in normal transportation, cause fires through friction or retained heat, and burn vigorously and/or persistently when ignited.
DOT Class C	Explosives Classification	Manufactured articles that may contain Class A/B explosives in restricted quantities, minimum explosion hazard.
Drag	Residual Brake Pad Friction on Rotor	Residual brake friction can cause brake overheating and component expansion which can impair brake operations
Driver	or Device Driver	Software that controls a specific hardware device, such as a DAQ board, printer, monitor, etc.
Driving Coefficient		Ratio of driving force to vertical load.
Drop Test(er)	A test(er) using a free fall method to shock a component with a measured pulse.	Used to release a component from a specified height onto an anvil surface (steel plate or specifically damped surface) to determine damages or to impinge a specific acceleration pule on a component.
DTC	Diagnostic Trouble Code	A formal name for system-detected error codes.
Dump		Mechanical: A function that relieves pressure or vacuum in a particular circuit (typically used when describing CC servo vacuum or braking wheel cylinder pressures, etc.). Electronic: A function that describes downloading all the data in a particular place, such as RAM or EEPROM.
DUR	Duration. Also see DWL.	Duration time of sensor switch closure. Sometimes stated as DUR_{min}, which is the minimum time during which the sensor switch should have been closed.
Dust Boot		Outer seal in wheel cylinder to prevent dust and road grit from entering piston bore and affecting piston seal. Also, seal on floating-caliper slider pins.
DUT	Device Under Test	Typical term used in industry to describe a subject device in a test apparatus.
DVM	Digital Voltmeter	Electronic test meter, combining current, voltage, resistance, etc., measurement functions that does not significantly load the measured circuit. Also called DMM. This not the same as a legacy analog volt meter which loads the measured circuit.
DWL	Dwell. Also see DUR.	Duration time of sensor switch closure. Sometimes stated as DWL_{min}, which is the minimum time during which the sensor switch should have been closed.
EBCM	Electronic Brake Control Module	A term used to describe an electronic controller in an ABS system.
ECT	Electronically Controlled Transmission	A vehicle transmission whose shift (and other) functions are controlled by electromechanical components, actuated by a transmission ECU, or a section of the PCM.
ECU	Electronic Control Unit	A generic term for electronic control device (e.g., Computer or Controller). An ECU performs functional activation calculations and continually checks the functional readiness of a vehicle system.
Edge Detection		Imaging: A technique that locates an edge by examining an image for abrupt changes in pixel values.
Edge Detection		Electronics: A circuit technique that triggers on an input waveform edge (rising or falling) versus an absolute voltage level.
EDRU	Event Data Retrieval Unit	Assembly of a scanner, umbilical cables, and small printer that is used to download DERM/SDM EEPROM engineering level crash data. (G.M.)
EEPROM	Electrically Erasable Programmable Read Only Memory	A section of memory that retains data even when power is removed from the ECU. Read out by special scan tools through an ECU serial port. Such devices (EAROM, EEPROM, flash memory) are called nonvolatile memory.
EHCU	Electro Hydraulic Control Unit	A term used to describe an electronic controller in an ABS system.
EMCC	Electro-Motor Cruise Control	A cruise control device that used a motor and clutch to control the throttle of a vehicle engine (as distinguished from a vacuum servo CC system).
EMI	Electro Magnetic Interference	Electro magnetic energy that can cause unwanted performance of a system or an ECU.
EMI Tests		Exposure to electromagnetic interference with evaluation of effects.

Name/Acronym	Description	Function
Energy Capacitor		A device to store enough energy to deploy air bag in case of power failure to system during crash. Usually good for approximately 1 s.
Energy Reserve Storage Device		Device to store enough energy to deploy air bag in case of power failure to system during crash. Usually good for approximately 1 s. The electrical device is usually a capacitor that is charged to a higher-than-battery voltage by a built in DC-DC converter.
Engineering Units		Specification of the physical quantities of interest. Examples are volts, amps, psi, mph, kph, gpm, gps, etc.
EPROM	Erasable Programmable Read Only Memory	This type of memory requires exposure to ultraviolet wavelengths in order to erase previous data. Also known as PROM.
Error Code		Code saved in ECU memory after ECU has detected an abnormal condition. Modern terminology is Diagnostic Trouble Code (DTC).
ESD	Electrostatic Discharge	Static charge dissipation that can cause damage to electronic circuits.
ETR	Emergency Tensioning Retractor	Electrically ignited gas piston to increase the tension in the seat belt and remove slack just after a crash is detected and before an occupant loading occurs, thus holding passenger(s) firmly in seat during a crash impulse.
Filter (Assembly) (Mechanical)		A construction of ports, and wire and mesh material that absorbs heat and prevents solid particles from exiting an air bag inflator.
Filter (Electrical)		An electrical circuit to suppress (attenuate) unwanted signal frequencies from passing through a circuit. Used to prevent aliasing (false signal generation) associated with certain A/D sampling rates versus signal frequencies.
Floating-Caliper		Disk brake caliper that uses a single-side piston, requiring caliper to slide (compensate) as disk pad friction material wears.
Frequency		The number of periods of harmonic motion (cycles of vibration, etc.) occurring per unit time. Usual units are Hertz (Hz), which are cycles per second. Applies to mechanical objects and electrical signals.
Freeze Frame		A set of associated data saved in nonvolatile memory to provide the conditions existing as a particular DTC is confirmed and also saved in nonvolatile memory.
Gas Generant		A solid material ignited by the squib/igniter/initiator to produce gas that inflates the folded air bag envelope.
Generant		Also called inflator, which burns to create the gas volume that inflates the folded air bag envelope.
GPIB	General Purpose Interface Bus	A type of data bus used by electrical test equipment.
Gray Zone		SRS: The region between Must Fire and Must Not Fire where performance is not guaranteed. Also see Must Fire and Must Not Fire. Electrical Binary Switching Circuits: The region between specified or defined output responses. When the voltage input to a binary electrical switching circuit is in the gray zone, the output can be either a "1" or a "0" (and is considered undefined).
Ground		An electrically neutral wire that serves as a common reference point for an electrical system. Derived from the concept of having the same common potential as the surrounding environment (earth). In power wiring, ground is normally, a noncurrent-carrying circuit intended for safety (e.g., ground- fault circuit-interrupters).
Gs		Acceleration/deceleration of Gravity. 32.17 feet/s^2, 21.9 mph/s, 9.81 m/s^2, 35.3 kph/s^2. *Gs* × time is used as a measure of impact impulse.
Half Sine		Waveform model of crash impulse or sensor test impulse.
Hard Pedal		A brake pedal that feels high and hard, not firmly compliant as is the usual feel with boosted brakes.
Haversine		A waveform model of crash impulse or sensor test impulse.
HCMOS	High-Density Complementary Metal Oxide Semiconductor	A semiconductor technology chosen for its low power consumption and good noise immunity.
Hexadecimal		Base-16 numbering system (0 to 9, A to F) for data bytes. Most automotive black box (computer memory) data is read out in this form and then has to be interpreted into engineering units. The interpretations are generally defined by SAE J2178-2 as "SLOT" definitions. Also see "SLOT" and (SAE J2178-2).
HHT	Hand Held Tester	Scanner type device to readout and program certain Bosch SRS ECUs.

Name/Acronym	Description	Function
HIC	Head Injury Criteria	A calculation of head resultant- acceleration (deceleration) integrated over a worst case crash time period.
High-Pass Filter		A circuit that attenuates low-frequency components in an analog signal.
http	Hypertext Transfer Protocol	The protocol that negotiates document delivery to a web browser from a web server.
Hz	Hertz	1 Hz = 1 cycle per s. An engineering unit to measure frequency.
I/O	Input/Output	Used to describe a bidirectional pin or function.
I/O Address		A specific hardware circuit and software value that is used to distinguish between the different electronic units in a system.
IC	Integrated Circuit	A complex device combining many individual electronic circuits and switches into one semiconductor die or chip. Modern ICs can have logic, filter, memory, and communications functions all on the same die.
Igniter		Also called Initiator or Squib. A pyrotechnic device, actuated by an electrical current, which ignites the inflator charge.
Impulse Tester		Simple scanner to count lamp blink codes.
Impulse		A change in momentum caused by a force. Evaluated as the average force × the time over which it acts.
Inflator	Also: generant	Chemical charge that burns to generate gas to inflate air bag. Requires "Igniter."
Initiator	Also: igniter, squib	A pyrotechnic device, actuated by an electrical current, which ignites the inflator charge.
Interrupt Handler		The software routine that takes care of an interrupt's request for service.
Interrupt		A signal that requires immediate attention from a computer's CPU.
Interrupt Vector		A type of interrupt that immediately points a computer to a new series of instructions.
IRS	Inflatable Restraint System	Also see SRS, SIR, etc.
Jerk		A term used to denote the time rate of change of acceleration. Used as a predictor of probable crash severity.
Julian Day Number		Obtained by counting days from the starting point of noon on 1 January 4713 B.C. One way of telling what day it is with the least possible ambiguity.
K byte, kb		A kilobyte of memory (1024 bytes). Four kb = 4096 bytes.
Knee Bolster, Bar, Bumper		A cushion device under the steering wheel to prevent occupant submarining and to lessen femur and tibia loads.
LAN	Local Area Network	Generic term used for fixed-location area networks (as distinguished from vehicle networks, etc.).
Latched Code		A DTC saved in memory after ignition cycle in which it occurred. Usually disables the system in which it occurred and sets a warning light (i.e, ABS, SRS function, etc).
LCD	Liquid Crystal Display	A flat panel display having higher electronic efficiency than lagacy CRTs, etc.
Leading		Item contacted first as the wheel rotor turns forward.
LED	Light Emitting Diode	A special form of electrical diode that emits light in the forward-current flow direction.
Lining		Friction material attached to pad backing plate in brake systems.
Lip Seal		Unidirectional hydraulic seal used in brake systems. Its design forces increased sealing with increased pressure in the sealing direction.
Low-Pass Filter		A circuit that attenuates the high-frequency components in an analog signal. Also see aliasing.
LSB	Least Significant Byte/Bit	The minimum (units) count of a value in a byte of data. The SLOT conversion resolution is often expressed as a value in engineering units per LSB (min count).
LSPV	Load Sensing Proportioning Valve	A device that ratios (proportions) the relative pressure applied to the rear brakes dependent on vehicle weight distribution.
Master Cylinder		Foundation Brake piston/cylinder that provides hydraulic pressure to the wheel cylinders.
MCU	Microcontroller Unit	Integrated circuit component incorporating arithmetic processing, memory, and interface circuits.

Name/Acronym	Description	Function
Metering Valve		Pressure control valve used to hold off front (disk) apply till rear (drums) are pressurized (called metering function). Used to improve braking balance in light braking applications.
MIL	Malfunction Indicator Lamp	Instrument cluster warning lamp to alert driver to system malfunction. (ABS, SRS, etc.)
Module Assembly		An assembly consisting of the inflator assembly, bag, mounting plates or housing, and a protective cover.
Monotonicity		A characteristic of a properly operating DAC or ADC in which the output increases in a continuous and ratiometric fashion as the respective inputs increase. Also applies to decreases.
MOSFET	Metal Oxide Semiconductor Field Effect Transistor	A semiconductor device that operates using a change in conductivity caused by the varying electrical field created by a control electrode (gate) insulated from its substrate by a silicon oxide.
MPG	Miles Per Gallon	A term for fuel efficiency over distance.
MPU	Microprocessor Unit	An integrated circuit device that forms the central control unit of a vehicle system ECU.
ms	milliseconds	1/1000 of a second = 10^{-3}. Used as a measure of time when describing SRS crash events. Most crash events occur in 80 to 120 ms, although some may last as long as 200 ms.
MSB	Most Significant Byte/Bit	The maximum value bit in a byte of data. Also see LSB.
Multiple Parameter Byte		A data byte where more than one condition or value is contained within a hexadecimal value (or byte).
Must Not Fire		Threshold value, stated in units of Delta V, or $Gs \times s$, below which the sensor must not close or the system must not fire. The region between Must Fire and Must Not Fire is known as the Gray Zone, where performance is not guaranteed.
Must Fire		Threshold value (stated in units of Delta V, or $Gs \times s$) above which the sensor must close or the system must fire. The region between Must Fire and Must Not Fire is known as the Gray Zone, where performance is not guaranteed.
Nibble		Half a byte (4 bits).
Noise Floor	Also: Noise Level	1) The level below which no information can be obtained from a signal. A signal that occurs below a noise floor is permanently lost. 2) The minimum discernable signal that can be detected by a receiver.
NRZ	Nonreturn to Zero	A form of data coding used in serial communications to maximize the data throughput per signal line.
NTSC	National Television System Committee. See also: PAL, RS-170	A standard for encoding color video signals. The standard is used in North America, Japan, and most of South America.
Nyquist Sampling Theorem		A theorem that states that if you sample a signal at a rate, f, the samples will contain no information about signals with frequency components above $f/2$.
ODI	Office of Defects Investigation, NHTSA	The branch of NHTSA that investigates potential vehicle defects.
OEM	Original Equipment Manufacturer	The source manufacturer of a component or system. Used to distinguish from a reseller or dealer, etc.
Ohms	Resistance unit	A measure of resistance to electrical current flow. Units are Ohms (Ω). A potential of one volt applied across one ohm will produce a current flow of one ampere.
Oscillograph		A time marked X-axis trace of Y-axis engineering parameters recorded on a hard copy output.
PAL	Phase Alternation Line. See also: NTSC, RS-170.	A composite color video standard used in Western Europe, India, China, and some Middle Eastern countries.
PCB	Printed Circuit Board	A phenolic or glass epoxy carrier with printed wiring interconnects between soldered components, forming an electronic assembly.
PCM	Powertrain Control Module	An engine EFI Controller often combining CC, EFI, ECT functions.
PDOF	Principal Direction of Force	A resultant vector force applied by object(s) colliding with a vehicle. A planar PDOF is the resultant of X-axis and Y-axis forces.
Pellet	also: pill, tablet	A compacted unit of gas generant that is used in the inflator.
Period	time, ms, etc.	The time period of one complete "cycle," i.e., the time it takes to complete sequence of regular-periodic actions such as a wheel oscillation bounce, etc.

Name/Acronym	Description	Function
Pigtail		A length of wire harness that has a connector installed on one end.
Piston		Actuated component inside brake cylinder bore. Wheel cylinder moves out with hydraulic pressure inside bore. Master-cylinder push-rod actuation caused hydraulic pressure to be generated inside bore (and then transmitted to wheel-cylinders).
Pixel		1) The fundamental picture element in a digital image. 2) The coordinate unit used to define the horizontal location of a pixel in an image. Pixel is actually an acronym for "picture element."
Polling		A round robin canvassing of inputs to a computer to determine which ones are active. Generally synchronized in software to a clock or external trigger.
Porosity		The gas permeability of the air bag fabric. Has to be considered along with vent holes when determining the deflation characteristics of air bags.
Port		A communications connection on a computer or a remote controller.
Primary Sensor		A sensing element employed to independently detect frontal type impacts.
PROM	Programmable Read Only Memory	A nonvolatile memory that retains its contents after power is removed. PROMs can be programmed in manufacturing or (usually once) in the field. In control ECUs, PROMS are usually used to hold program information and EAROM/EEPROM, flash memory can be used to hold calibration-specific information. That way, calibrations can be changed electronically without a physical unit change.
Proportioning Valve		Valve to regulate the pressure to the rear brakes to prevent rear wheel lockup during hard brake application.
ps	Picoseconds	1/1 000 000 000 of a second = 10 ^{9}.
psec	Picoseconds	1/1 000 000 000 of a second = 10^{-9}.
Pulse Width (PW)		The time from initial "0" (or minimum-threshold) until ending "0" (or minimum-threshold).
PWM	Pulse Width Modulation	Method of controlling valve flow rate.
RABS	Rear Anti Lock Brake System	Simplified form of antilock braking system that controls rear wheels only.
RAM	Random Access Memory	General form of computer memory, which loses its data contents when power is removed. Also see PROM.
Readiness Indicator	also: MIL	A device in the instrument panel that indicates the functionality of the electrical circuits by lighting up for a short time period after each ignition turn-on.
Recorder		A memory device in vehicle systems that records selected pre-crash and/or crash information.
RES	Resistance	Measure of resistance to electrical current flow. Units are Ohms (Ω).
Reservoir (Brake)		Fluid container, usually on top of master cylinder, gravity feeding into compensating port and rear chamber ports. Reservoir, but can also be remote container feeding master cylinder via hydraulic hose.
Residual Pressure		Small brake circuit pressure, usually < 10 psi, left in circuit to prevent trapped air from entering circuit. Used with drum brakes. Not used with disk brakes.
Residual Pressure Check Valve		Valve at master cylinder outlet to maintain small wheel brake circuit pressure, usually <10 psi, to prevent trapped air from entering circuit. Used with drum brakes.
RFI	Radio Frequency Interference	Radio frequency energy that can have an effect on other equipment.
ROM	Read Only Memory	This type of memory is programmed during device manufacture and cannot subsequently be altered.
Rotor	Disk Brake Component	Disk-shaped friction apply surface which is squeezed by the disk caliper pads to provide stopping torque.
R_{sense}	Resistance across open sensor.	Telltale resistance to electrical current flow across open sensor. Used by the diagnostic ECU to assure that the sensor is connected, but does not provide enough current to fire the air bag. Units are Ohms (Ω).
RWAL	Rear Wheel Anti Lock	See RABS.
SAE	Society of Automotive Engineers	Organization of engineering professionals whose interests concern vehicle technologies.
Safing Sensor		See Arming Sensor.
Sample and Hold	SHA (sample and hold amplifier)	A circuit that acquires an analog voltage and stores it temporarily in a capacitor.

Name/Acronym	Description	Function
Scale Factor		Specification of the Engineering Units value of each count of a digital value (usually output by an A/D converter).
SCI	Serial Communications Interface	Used as an Input/Output device or function of a microcontroller device.
SCSI	Small Computer Standard Interface	Used as a standard interface to computer peripheral devices such as hard drives, CD Roms, etc.
SDM	Sensing and Diagnostic Module	Integral sensor module to determine if crash pulse is sufficient to deploy air bags. Also contains diagnostic and crash data storage functions.
Secondary Latch		A redundant lock on air bag system electrical connectors to assure wiring harness immunity from vehicle vibration, etc. Normally, this secondary lock must be removed first, in order to allow disassembly of the actual electrical harness connector. Also called connector assurance latch.
Sensitivity		A measure of the minimum change in an input signal that an instrument can detect.
Sensor	Small sealed unit, generally about the size of a pack of cigarettes.	Device to detect an acceleration/deceleration pulse, can also be called a transducer. Sensors can be electromechanical, with moving mechanical switch elements, or they can be solid state devices with micromachined reaction pendulums. In both cases, the sensors produce an electrical output in response to the deceleration impulse. Electromechanical sensors produce a binary response (1, 0, switch closure). Accelerometers produce a continuous voltage output proportional to the deceleration pulse magnitude. The time integral of that output is called the deceleration impulse.
Shorting Connector	also: shorting bar, shorting clip	Special harness connector that shorts the disconnected squib/igniter component leads to prevent stray electrical pulse input to that component. Used for Squib connections to prevent inadvertent firing from static electricity, etc. Also used in SRS ECU connectors to force SRS warning lamp on if SRS ECU is removed.
SI	International System of Units	kg, ms, N, N-m, m, etc.
Signal-to-Noise Ratio	SNR	Term used in communications to quantify the % of noninformation (noise or corruption) contained in a information signal of interest.
Signed Floating Point		A byte packet, where a combination of bytes represent a sign, exponent, and fractional part of an engineering unit, depending upon a value resolution specification.
SIP	Single In-line Package	Describes the pin layout on an MPU.
SIR	Supplemental Inflatable Restraint	G. M. System Identification for SRS.
Slip		Percentage of difference between the circumferential speed of a tire vs. the longitudinal speed of the vehicle. Zero braking occurs at 0% slip. Maximum braking occurs at 12 to 14% slip. Locked tires indicate 100% slip.
Slip-Ring and Brushes	Rotary connector at steering wheel. Spring-tensioned brushes (4) sliding on concentric commutators under steering wheel.	Connects driver air bag to sensors and ECU, allowing driver to turn the steering wheel. Largely supplanted by clock springs (multi-turn spiral springs) in modern vehicles to accomplish the same purpose.
SLOT	Scaling, Limit, Offset, Transfer Function	SLOT, in effect, defines the engineering units translation of a raw parameter value transmitted on the network (SAE J2178-2).
Snapshot		Recording function built into some test scanners that records vehicle conditions at the time of a trap parameter. Trap parameters can be a specific DTC manual, or a speed threshold, etc. error code storage. A Snapshot can be thought of as the scanner dual of freeze frames saved in on-board vehicle ECUs.
Soft Pedal		Brake pedal that has high travel and/or feels mushy, not firm.
SPI	Serial Peripheral Interface	A term used to describe a section of microprocessor architecture dealing with RS 232 or other serial data interface.
Spike		A transient disturbance of an electrical circuit. Can be caused by load variations on the AC power line, among other things.

Name/Acronym	Description	Function
Spring Rate		The unit change of force to compress (or extend) a spring relative to the unit deflection.
Squeal, inadvertent		Noise generated when the brakes are applied. Caused by some particular pad materials as pressurized against the rotors.
Squeal, intentional		Noise generated by steel extensions when pad lining thickness is low to warn the driver to have the brakes serviced. Happens when the brakes are applied. Caused by some particular pad friction materials.
Squib		Also called Initiator or Igniter. A pyrotechnic device, actuated by an electrical current, which ignites the inflator charge.
SRS Lamp		Instrument Cluster Warning Lamp to alert driver to SRS system malfunction. Also called MIL.
SRS	Supplemental Restraint System	Generic identification. Also see IRS, SIR, ABRS, ACRS, etc.
Stability		The ability of an instrument or sensor to maintain a constant output when a constant input is applied. Includes signal integrity over time and temperature.
State Encoded Byte		State Encoded Byte, where the data can represent a coding that stands for a condition or state of a parameter, system or a device. States can include day of the week, day of the month, transmission gear engaged, operational mode, etc.
Stop Lamp Switch		Switch actuated by operator actuation of brake pedal. Can be hydraulic (i.e., on master cylinder circuit) or mechanical (i.e., on brake pedal swing arm). This switch is used to actuate stop lamps on rear of vehicle.
Surge		A sudden change (usually an increase) in the voltage on a power line. A surge is similar to a spike, but it lasts longer.
Sync		The portion of a video signal that indicates the end of either a field or a line of video information, thus providing frame sync[hronization]. Also called synch. Other uses include the name of a pulse that triggers electronic or video event data captures.
Tank Test		The firing of an air bag inflator into a closed volume at a specific temperature. Used as a measure of air bag inflator aggressivity or power.
TCC	Torque Converter Clutch	Lockup feature used in automatic transmission hydraulic component to increase transmission efficiency.
Tether(s)		Ribbons or straps inside the air bag envelope to limit the outward air bag envelope deploy distance after it is fired. Tethers are also used to "shape" the dynamic unfolding pattern of large passenger air bags, i.e., prevent face contact while allowing chest contact in the initial expansion phase.
t_{event}		The time duration encompassing an event under consideration.
Threshold		A level above which a system is triggered, or a level below which a system may be reset.
Throughput Rate		The maximum repetitive rate at which a data-conversion system, or a data communication system can operate with a specified accuracy.
Torque (brakes)		Measure of brake power at wheel axle. Usually Given in ft-lb.
Torque (mechanical)		Measure of attaching bolt tightness. Can affect sensor response. Usually given in in-lb. Note that tightening-torques are the only valid measure of an already-assembled bolt torque.
Torso Bag		A portion of the air bag that provides additional restraint to the upper body. See "tethers."
T_{pulse}		Time duration of crash acceleration pulse over a min threshold. Usually given in ms.
Trailing		Item contacted last as the wheel rotor turns forward.
TSB	Technical Service Bulletin	Notification sent to dealerships by manufacturers to notify them of a potential problem or servicing change.
TTC	Time To Close	Time (ms) after detecting a_{thresh} for sensor to respond (close switch).
TTF	Time To Fire	Time (ms) after input pulse passes a_{thresh} for sensor to respond (close switch).
TTL	Transistor-Transistor Logic	Standard form of bipolar transistor logic used since the early 1970s. Now largely superceded by CMOS. The TTL standard 0 and +5V signal levels are still pervasive in the industry.

Name/Acronym	Description	Function
Tunnel Sensor		Usually a discriminating sensor on the floorpan tunnel. Is also used to describe a combined arming/discriminating sensor on the floorpan tunnel.
UART	Universal Asynchronous Receiver Transmitter	Device used to control serial communications.
Unsigned Numeric Byte		Unsigned Numeric, where the decimal interpreted value represents an engineering unit, depending upon a value resolution specification (e.g., each count = 0.5 mph).
USB	Universal Serial Bus	Advanced serial port device used in modern computers. One of the few formats standard between Apple and IBM environment machines.
UUT	Unit Under Test	See DUT
VAC	Velocity At Close	Measurement of change in velocity at the time sample period of (electromechanical) sensor switch contact closure. Also can be Voltage, Alternating Current
Vacuum Depletion		The condition where booster vacuum necessary to amplify brake pedal forces is diminished or absent.
VCO	Voltage Controlled Oscillator	Electronic circuit used in certain signal modulation and conditioning circuits.
Velocity		A term used to denote the time rate of change of distance traveled. Typical units are: mph, fps, kph, mps, etc.
Vents		The holes in some air bag designs that control the expulsion of gas from the bag to provide controlled occupant deceleration.
VIN	Vehicle Identification Number	A 17-digit vehicle identification with specific position codes (country, manufacturer, model-year, etc.).
VSS	Vehicle Speed Sensor	Usually a magnetic or hall-effect pulse generator usually on driveshaft or transmission tailstock. Sometimes on differential carrier or speedometer cable. Used for overall vehicle speed for cruise control, PCM, PZM (BCM), Remote Keyless Entry, or Autolock inputs. VSS can also be optical.
Warning Indicator		See MIL
Warning Valve		Shuttle-type valve used to close switch (Brake MIL) to alert driver to pressure imbalance in brake circuit master cylinder output.
Watchdog		Circuit used in microcontrollers to detect electronic lockup or freeze. Also: COP.
Wired-OR		A means of connecting outputs together such that the resulting composite output state is the logical OR of the individual outputs.
Word		In computer jargon, usually 2 bytes (16 bits).
WSS	Wheel Speed Sensor	Usually a magnetic pulse generator at each monitored wheel. Provides analog pulse train proportional to individual wheel speed. WSS devices can also be optical (especially for test fixtures).

APPENDIX A.2.1

Conversion Factors by Unit MPH

1mile =>	5280.0000	ft	63360.0000	in	1.6094	km
1hr =>	60.0000	min	3600.0000	sec		

MPH	ft/sec	ft/ms	ms/ft	ms/in	in/ms	KPH	m/s	m/ms	ms/m	ms/cm	cm/ms
1	1.4667	0.0015	681.8182	56.8182	0.0176	1.6094	0.4471	0.0004	2236.8585	22.3686	0.0447
2	2.9333	0.0029	340.9091	28.4091	0.0352	3.2188	0.8941	0.0009	1118.4292	11.1843	0.0894
3	4.4000	0.0044	227.2727	18.9394	0.0528	4.8282	1.3412	0.0013	745.6195	7.4562	0.1341
4	5.8667	0.0059	170.4545	14.2045	0.0704	6.4376	1.7882	0.0018	559.2146	5.5921	0.1788
5	7.3333	0.0073	136.3636	11.3636	0.0880	8.0470	2.2353	0.0022	447.3717	4.4737	0.2235
6	8.8000	0.0088	113.6364	9.4697	0.1056	9.6564	2.6823	0.0027	372.8097	3.7281	0.2682
7	10.2667	0.0103	97.4026	8.1169	0.1232	11.2658	3.1294	0.0031	319.5512	3.1955	0.3129
8	11.7333	0.0117	85.2273	7.1023	0.1408	12.8752	3.5764	0.0036	279.6073	2.7961	0.3576
9	13.2000	0.0132	75.7576	6.3131	0.1584	14.4846	4.0235	0.0040	248.5398	2.4854	0.4024
10	14.6667	0.0147	68.1818	5.6818	0.1760	16.0940	4.4706	0.0045	223.6858	2.2369	0.4471
11	16.1333	0.0161	61.9835	5.1653	0.1936	17.7034	4.9176	0.0049	203.3508	2.0335	0.4918
12	17.6000	0.0176	56.8182	4.7348	0.2112	19.3128	5.3647	0.0054	186.4049	1.8640	0.5365
13	19.0667	0.0191	52.4476	4.3706	0.2288	20.9222	5.8117	0.0058	172.0660	1.7207	0.5812
14	20.5333	0.0205	48.7013	4.0584	0.2464	22.5316	6.2588	0.0063	159.7756	1.5978	0.6259
15	22.0000	0.0220	45.4545	3.7879	0.2640	24.1410	6.7058	0.0067	149.1239	1.4912	0.6706
16	23.4667	0.0235	42.6136	3.5511	0.2816	25.7504	7.1529	0.0072	139.8037	1.3980	0.7153
17	24.9333	0.0249	40.1070	3.3422	0.2992	27.3598	7.5999	0.0076	131.5799	1.3158	0.7600
18	26.4000	0.0264	37.8788	3.1566	0.3168	28.9692	8.0470	0.0080	124.2699	1.2427	0.8047
19	27.8667	0.0279	35.8852	2.9904	0.3344	30.5786	8.4941	0.0085	117.7294	1.1773	0.8494
20	29.3333	0.0293	34.0909	2.8409	0.3520	32.1880	8.9411	0.0089	111.8429	1.1184	0.8941
21	30.8000	0.0308	32.4675	2.7056	0.3696	33.7974	9.3882	0.0094	106.5171	1.0652	0.9388
22	32.2667	0.0323	30.9917	2.5826	0.3872	35.4068	9.8352	0.0098	101.6754	1.0168	0.9835
23	33.7333	0.0337	29.6443	2.4704	0.4048	37.0162	10.2823	0.0103	97.2547	0.9725	1.0282
24	35.2000	0.0352	28.4091	2.3674	0.4224	38.6256	10.7293	0.0107	93.2024	0.9320	1.0729
25	36.6667	0.0367	27.2727	2.2727	0.4400	40.2350	11.1764	0.0112	89.4743	0.8947	1.1176
26	38.1333	0.0381	26.2238	2.1853	0.4576	41.8444	11.6234	0.0116	86.0330	0.8603	1.1623
27	39.6000	0.0396	25.2525	2.1044	0.4752	43.4538	12.0705	0.0121	82.8466	0.8285	1.2071
28	41.0667	0.0411	24.3506	2.0292	0.4928	45.0632	12.5176	0.0125	79.8878	0.7989	1.2518
29	42.5333	0.0425	23.5110	1.9592	0.5104	46.6726	12.9646	0.0130	77.1331	0.7713	1.2965
30	44.0000	0.0440	22.7273	1.8939	0.5280	48.2820	13.4117	0.0134	74.5619	0.7456	1.3412
31	45.4667	0.0455	21.9941	1.8328	0.5456	49.8914	13.8587	0.0139	72.1567	0.7216	1.3859
32	46.9333	0.0469	21.3068	1.7756	0.5632	51.5008	14.3058	0.0143	69.9018	0.6990	1.4306
33	48.4000	0.0484	20.6612	1.7218	0.5808	53.1102	14.7528	0.0148	67.7836	0.6778	1.4753
34	49.8667	0.0499	20.0535	1.6711	0.5984	54.7196	15.1999	0.0152	65.7900	0.6579	1.5200
35	51.3333	0.0513	19.4805	1.6234	0.6160	56.3290	15.6469	0.0156	63.9102	0.6391	1.5647
36	52.8000	0.0528	18.9394	1.5783	0.6336	57.9384	16.0940	0.0161	62.1350	0.6213	1.6094
37	54.2667	0.0543	18.4275	1.5356	0.6512	59.5478	16.5411	0.0165	60.4556	0.6046	1.6541
38	55.7333	0.0557	17.9426	1.4952	0.6688	61.1572	16.9881	0.0170	58.8647	0.5886	1.6988
39	57.2000	0.0572	17.4825	1.4569	0.6864	62.7666	17.4352	0.0174	57.3553	0.5736	1.7435
40	58.6667	0.0587	17.0455	1.4205	0.7040	64.3760	17.8822	0.0179	55.9215	0.5592	1.7882
41	60.1333	0.0601	16.6297	1.3858	0.7216	65.9854	18.3293	0.0183	54.5575	0.5456	1.8329
42	61.6000	0.0616	16.2338	1.3528	0.7392	67.5948	18.7763	0.0188	53.2585	0.5326	1.8776
43	63.0667	0.0631	15.8562	1.3214	0.7568	69.2042	19.2234	0.0192	52.0200	0.5202	1.9223
44	64.5333	0.0645	15.4959	1.2913	0.7744	70.8136	19.6704	0.0197	50.8377	0.5084	1.9670
45	66.0000	0.0660	15.1515	1.2626	0.7920	72.4230	20.1175	0.0201	49.7080	0.4971	2.0118
46	67.4667	0.0675	14.8221	1.2352	0.8096	74.0324	20.5646	0.0206	48.6274	0.4863	2.0565
47	68.9333	0.0689	14.5068	1.2089	0.8272	75.6418	21.0116	0.0210	47.5927	0.4759	2.1012
48	70.4000	0.0704	14.2045	1.1837	0.8448	77.2512	21.4587	0.0215	46.6012	0.4660	2.1459
49	71.8667	0.0719	13.9147	1.1596	0.8624	78.8606	21.9057	0.0219	45.6502	0.4565	2.1906
50	73.3333	0.0733	13.6364	1.1364	0.8800	80.4700	22.3528	0.0224	44.7372	0.4474	2.2353

51	74.8000	0.0748	13.3690	1.1141	0.8976	82.0794	22.7998	0.0228	43.8600	0.4386	2.2800
52	76.2667	0.0763	13.1119	1.0927	0.9152	83.6888	23.2469	0.0232	43.0165	0.4302	2.3247
53	77.7333	0.0777	12.8645	1.0720	0.9328	85.2982	23.6939	0.0237	42.2049	0.4220	2.3694
54	79.2000	0.0792	12.6263	1.0522	0.9504	86.9076	24.1410	0.0241	41.4233	0.4142	2.4141
55	80.6667	0.0807	12.3967	1.0331	0.9680	88.5170	24.5881	0.0246	40.6702	0.4067	2.4588
56	82.1333	0.0821	12.1753	1.0146	0.9856	90.1264	25.0351	0.0250	39.9439	0.3994	2.5035
57	83.6000	0.0836	11.9617	0.9968	1.0032	91.7358	25.4822	0.0255	39.2431	0.3924	2.5482
58	85.0667	0.0851	11.7555	0.9796	1.0208	93.3452	25.9292	0.0259	38.5665	0.3857	2.5929
59	86.5333	0.0865	11.5562	0.9630	1.0384	94.9546	26.3763	0.0264	37.9129	0.3791	2.6376
60	88.0000	0.0880	11.3636	0.9470	1.0560	96.5640	26.8233	0.0268	37.2810	0.3728	2.6823
61	89.4667	0.0895	11.1773	0.9314	1.0736	98.1734	27.2704	0.0273	36.6698	0.3667	2.7270
62	90.9333	0.0909	10.9971	0.9164	1.0912	99.7828	27.7174	0.0277	36.0784	0.3608	2.7717
63	92.4000	0.0924	10.8225	0.9019	1.1088	101.3922	28.1645	0.0282	35.5057	0.3551	2.8165
64	93.8667	0.0939	10.6534	0.8878	1.1264	103.0016	28.6116	0.0286	34.9509	0.3495	2.8612
65	95.3333	0.0953	10.4895	0.8741	1.1440	104.6110	29.0586	0.0291	34.4132	0.3441	2.9059
66	96.8000	0.0968	10.3306	0.8609	1.1616	106.2204	29.5057	0.0295	33.8918	0.3389	2.9506
67	98.2667	0.0983	10.1764	0.8480	1.1792	107.8298	29.9527	0.0300	33.3859	0.3339	2.9953
68	99.7333	0.0997	10.0267	0.8356	1.1968	109.4392	30.3998	0.0304	32.8950	0.3289	3.0400
69	101.2000	0.1012	9.8814	0.8235	1.2144	111.0486	30.8468	0.0308	32.4182	0.3242	3.0847
70	102.6667	0.1027	9.7403	0.8117	1.2320	112.6580	31.2939	0.0313	31.9551	0.3196	3.1294
71	104.1333	0.1041	9.6031	0.8003	1.2496	114.2674	31.7409	0.0317	31.5050	0.3151	3.1741
72	105.6000	0.1056	9.4697	0.7891	1.2672	115.8768	32.1880	0.0322	31.0675	0.3107	3.2188
73	107.0667	0.1071	9.3400	0.7783	1.2848	117.4862	32.6351	0.0326	30.6419	0.3064	3.2635
74	108.5333	0.1085	9.2138	0.7678	1.3024	119.0956	33.0821	0.0331	30.2278	0.3023	3.3082
75	110.0000	0.1100	9.0909	0.7576	1.3200	120.7050	33.5292	0.0335	29.8248	0.2982	3.3529
76	111.4667	0.1115	8.9713	0.7476	1.3376	122.3144	33.9762	0.0340	29.4323	0.2943	3.3976
77	112.9333	0.1129	8.8548	0.7379	1.3552	123.9238	34.4233	0.0344	29.0501	0.2905	3.4423
78	114.4000	0.1144	8.7413	0.7284	1.3728	125.5332	34.8703	0.0349	28.6777	0.2868	3.4870
79	115.8667	0.1159	8.6306	0.7192	1.3904	127.1426	35.3174	0.0353	28.3147	0.2831	3.5317
80	117.3333	0.1173	8.5227	0.7102	1.4080	128.7520	35.7644	0.0358	27.9607	0.2796	3.5764
81	118.8000	0.1188	8.4175	0.7015	1.4256	130.3614	36.2115	0.0362	27.6155	0.2762	3.6212
82	120.2667	0.1203	8.3149	0.6929	1.4432	131.9708	36.6586	0.0367	27.2788	0.2728	3.6659
83	121.7333	0.1217	8.2147	0.6846	1.4608	133.5802	37.1056	0.0371	26.9501	0.2695	3.7106
84	123.2000	0.1232	8.1169	0.6764	1.4784	135.1896	37.5527	0.0376	26.6293	0.2663	3.7553
85	124.6667	0.1247	8.0214	0.6684	1.4960	136.7990	37.9997	0.0380	26.3160	0.2632	3.8000
86	126.1333	0.1261	7.9281	0.6607	1.5136	138.4084	38.4468	0.0384	26.0100	0.2601	3.8447
87	127.6000	0.1276	7.8370	0.6531	1.5312	140.0178	38.8938	0.0389	25.7110	0.2571	3.8894
88	129.0667	0.1291	7.7479	0.6457	1.5488	141.6272	39.3409	0.0393	25.4188	0.2542	3.9341
89	130.5333	0.1305	7.6609	0.6384	1.5664	143.2366	39.7879	0.0398	25.1332	0.2513	3.9788
90	132.0000	0.1320	7.5758	0.6313	1.5840	144.8460	40.2350	0.0402	24.8540	0.2485	4.0235
91	133.4667	0.1335	7.4925	0.6244	1.6016	146.4554	40.6821	0.0407	24.5809	0.2458	4.0682
92	134.9333	0.1349	7.4111	0.6176	1.6192	148.0648	41.1291	0.0411	24.3137	0.2431	4.1129
93	136.4000	0.1364	7.3314	0.6109	1.6368	149.6742	41.5762	0.0416	24.0522	0.2405	4.1576
94	137.8667	0.1379	7.2534	0.6044	1.6544	151.2836	42.0232	0.0420	23.7964	0.2380	4.2023
95	139.3333	0.1393	7.1770	0.5981	1.6720	152.8930	42.4703	0.0425	23.5459	0.2355	4.2470
96	140.8000	0.1408	7.1023	0.5919	1.6896	154.5024	42.9173	0.0429	23.3006	0.2330	4.2917
97	142.2667	0.1423	7.0291	0.5858	1.7072	156.1118	43.3644	0.0434	23.0604	0.2306	4.3364
98	143.7333	0.1437	6.9573	0.5798	1.7248	157.7212	43.8114	0.0438	22.8251	0.2283	4.3811
99	145.2000	0.1452	6.8871	0.5739	1.7424	159.3306	44.2585	0.0443	22.5945	0.2259	4.4259
100	146.6667	0.1467	6.8182	0.5682	1.7600	160.9400	44.7056	0.0447	22.3686	0.2237	4.4706

APPENDIX A.2.2

Conversion Factors by Unit KPH

1 km => 1000.00 m 100000.00 cm 0.62136 mi 5280.00 ft 63360.00 in
1hr => 60.00 min 3600.00 sec

KPH	m/s	m/ms	ms/m	ms/cm	cm/ms	MPH	ft/sec	ft/ms	ms/ft	ms/in	in/ms
1	0.2778	0.0003	3600.0000	36.0000	0.0278	0.6214	0.9113	0.0009	1097.2998	91.4416	0.0109
2	0.5556	0.0006	1800.0000	18.0000	0.0556	1.2427	1.8227	0.0018	548.6499	45.7208	0.0219
3	0.8333	0.0008	1200.0000	12.0000	0.0833	1.8641	2.7340	0.0027	365.7666	30.4805	0.0328
4	1.1111	0.0011	900.0000	9.0000	0.1111	2.4854	3.6453	0.0036	274.3249	22.8604	0.0437
5	1.3889	0.0014	720.0000	7.2000	0.1389	3.1068	4.5566	0.0046	219.4600	18.2883	0.0547
6	1.6667	0.0017	600.0000	6.0000	0.1667	3.7282	5.4680	0.0055	182.8833	15.2403	0.0656
7	1.9444	0.0019	514.2857	5.1429	0.1944	4.3495	6.3793	0.0064	156.7571	13.0631	0.0766
8	2.2222	0.0022	450.0000	4.5000	0.2222	4.9709	7.2906	0.0073	137.1625	11.4302	0.0875
9	2.5000	0.0025	400.0000	4.0000	0.2500	5.5922	8.2020	0.0082	121.9222	10.1602	0.0984
10	2.7778	0.0028	360.0000	3.6000	0.2778	6.2136	9.1133	0.0091	109.7300	9.1442	0.1094
11	3.0556	0.0031	327.2727	3.2727	0.3056	6.8350	10.0246	0.0100	99.7545	8.3129	0.1203
12	3.3333	0.0033	300.0000	3.0000	0.3333	7.4563	10.9359	0.0109	91.4416	7.6201	0.1312
13	3.6111	0.0036	276.9231	2.7692	0.3611	8.0777	11.8473	0.0118	84.4077	7.0340	0.1422
14	3.8889	0.0039	257.1429	2.5714	0.3889	8.6990	12.7586	0.0128	78.3786	6.5315	0.1531
15	4.1667	0.0042	240.0000	2.4000	0.4167	9.3204	13.6699	0.0137	73.1533	6.0961	0.1640
16	4.4444	0.0044	225.0000	2.2500	0.4444	9.9418	14.5812	0.0146	68.5812	5.7151	0.1750
17	4.7222	0.0047	211.7647	2.1176	0.4722	10.5631	15.4926	0.0155	64.5470	5.3789	0.1859
18	5.0000	0.0050	200.0000	2.0000	0.5000	11.1845	16.4039	0.0164	60.9611	5.0801	0.1968
19	5.2778	0.0053	189.4737	1.8947	0.5278	11.8058	17.3152	0.0173	57.7526	4.8127	0.2078
20	5.5556	0.0056	180.0000	1.8000	0.5556	12.4272	18.2266	0.0182	54.8650	4.5721	0.2187
21	5.8333	0.0058	171.4286	1.7143	0.5833	13.0486	19.1379	0.0191	52.2524	4.3544	0.2297
22	6.1111	0.0061	163.6364	1.6364	0.6111	13.6699	20.0492	0.0200	49.8773	4.1564	0.2406
23	6.3889	0.0064	156.5217	1.5652	0.6389	14.2913	20.9605	0.0210	47.7087	3.9757	0.2515
24	6.6667	0.0067	150.0000	1.5000	0.6667	14.9126	21.8719	0.0219	45.7208	3.8101	0.2625
25	6.9444	0.0069	144.0000	1.4400	0.6944	15.5340	22.7832	0.0228	43.8920	3.6577	0.2734
26	7.2222	0.0072	138.4615	1.3846	0.7222	16.1554	23.6945	0.0237	42.2038	3.5170	0.2843
27	7.5000	0.0075	133.3333	1.3333	0.7500	16.7767	24.6059	0.0246	40.6407	3.3867	0.2953
28	7.7778	0.0078	128.5714	1.2857	0.7778	17.3981	25.5172	0.0255	39.1893	3.2658	0.3062
29	8.0556	0.0081	124.1379	1.2414	0.8056	18.0194	26.4285	0.0264	37.8379	3.1532	0.3171
30	8.3333	0.0083	120.0000	1.2000	0.8333	18.6408	27.3398	0.0273	36.5767	3.0481	0.3281
31	8.6111	0.0086	116.1290	1.1613	0.8611	19.2622	28.2512	0.0283	35.3968	2.9497	0.3390
32	8.8889	0.0089	112.5000	1.1250	0.8889	19.8835	29.1625	0.0292	34.2906	2.8576	0.3499
33	9.1667	0.0092	109.0909	1.0909	0.9167	20.5049	30.0738	0.0301	33.2515	2.7710	0.3609
34	9.4444	0.0094	105.8824	1.0588	0.9444	21.1262	30.9852	0.0310	32.2735	2.6895	0.3718
35	9.7222	0.0097	102.8571	1.0286	0.9722	21.7476	31.8965	0.0319	31.3514	2.6126	0.3828
36	10.0000	0.0100	100.0000	1.0000	1.0000	22.3690	32.8078	0.0328	30.4805	2.5400	0.3937
37	10.2778	0.0103	97.2973	0.9730	1.0278	22.9903	33.7191	0.0337	29.6568	2.4714	0.4046
38	10.5556	0.0106	94.7368	0.9474	1.0556	23.6117	34.6305	0.0346	28.8763	2.4064	0.4156
39	10.8333	0.0108	92.3077	0.9231	1.0833	24.2330	35.5418	0.0355	28.1359	2.3447	0.4265
40	11.1111	0.0111	90.0000	0.9000	1.1111	24.8544	36.4531	0.0365	27.4325	2.2860	0.4374
41	11.3889	0.0114	87.8049	0.8780	1.1389	25.4758	37.3644	0.0374	26.7634	2.2303	0.4484
42	11.6667	0.0117	85.7143	0.8571	1.1667	26.0971	38.2758	0.0383	26.1262	2.1772	0.4593
43	11.9444	0.0119	83.7209	0.8372	1.1944	26.7185	39.1871	0.0392	25.5186	2.1265	0.4702
44	12.2222	0.0122	81.8182	0.8182	1.2222	27.3398	40.0984	0.0401	24.9386	2.0782	0.4812
45	12.5000	0.0125	80.0000	0.8000	1.2500	27.9612	41.0098	0.0410	24.3844	2.0320	0.4921
46	12.7778	0.0128	78.2609	0.7826	1.2778	28.5826	41.9211	0.0419	23.8543	1.9879	0.5031
47	13.0556	0.0131	76.5957	0.7660	1.3056	29.2039	42.8324	0.0428	23.3468	1.9456	0.5140
48	13.3333	0.0133	75.0000	0.7500	1.3333	29.8253	43.7437	0.0437	22.8604	1.9050	0.5249
49	13.6111	0.0136	73.4694	0.7347	1.3611	30.4466	44.6551	0.0447	22.3939	1.8662	0.5359
50	13.8889	0.0139	72.0000	0.7200	1.3889	31.0680	45.5664	0.0456	21.9460	1.8288	0.5468
51	14.1667	0.0142	70.5882	0.7059	1.4167	31.6894	46.4777	0.0465	21.5157	1.7930	0.5577
52	14.4444	0.0144	69.2308	0.6923	1.4444	32.3107	47.3891	0.0474	21.1019	1.7585	0.5687

53	14.7222	0.0147	67.9245	0.6792	1.4722	32.9321	48.3004	0.0483	20.7038	1.7253	0.5796
54	15.0000	0.0150	66.6667	0.6667	1.5000	33.5534	49.2117	0.0492	20.3204	1.6934	0.5905
55	15.2778	0.0153	65.4545	0.6545	1.5278	34.1748	50.1230	0.0501	19.9509	1.6626	0.6015
56	15.5556	0.0156	64.2857	0.6429	1.5556	34.7962	51.0344	0.0510	19.5946	1.6329	0.6124
57	15.8333	0.0158	63.1579	0.6316	1.5833	35.4175	51.9457	0.0519	19.2509	1.6042	0.6233
58	16.1111	0.0161	62.0690	0.6207	1.6111	36.0389	52.8570	0.0529	18.9190	1.5766	0.6343
59	16.3889	0.0164	61.0169	0.6102	1.6389	36.6602	53.7684	0.0538	18.5983	1.5499	0.6452
60	16.6667	0.0167	60.0000	0.6000	1.6667	37.2816	54.6797	0.0547	18.2883	1.5240	0.6562
61	16.9444	0.0169	59.0164	0.5902	1.6944	37.9030	55.5910	0.0556	17.9885	1.4990	0.6671
62	17.2222	0.0172	58.0645	0.5806	1.7222	38.5243	56.5023	0.0565	17.6984	1.4749	0.6780
63	17.5000	0.0175	57.1429	0.5714	1.7500	39.1457	57.4137	0.0574	17.4175	1.4515	0.6890
64	17.7778	0.0178	56.2500	0.5625	1.7778	39.7670	58.3250	0.0583	17.1453	1.4288	0.6999
65	18.0556	0.0181	55.3846	0.5538	1.8056	40.3884	59.2363	0.0592	16.8815	1.4068	0.7108
66	18.3333	0.0183	54.5455	0.5455	1.8333	41.0098	60.1476	0.0601	16.6258	1.3855	0.7218
67	18.6111	0.0186	53.7313	0.5373	1.8611	41.6311	61.0590	0.0611	16.3776	1.3648	0.7327
68	18.8889	0.0189	52.9412	0.5294	1.8889	42.2525	61.9703	0.0620	16.1368	1.3447	0.7436
69	19.1667	0.0192	52.1739	0.5217	1.9167	42.8738	62.8816	0.0629	15.9029	1.3252	0.7546
70	19.4444	0.0194	51.4286	0.5143	1.9444	43.4952	63.7930	0.0638	15.6757	1.3063	0.7655
71	19.7222	0.0197	50.7042	0.5070	1.9722	44.1166	64.7043	0.0647	15.4549	1.2879	0.7765
72	20.0000	0.0200	50.0000	0.5000	2.0000	44.7379	65.6156	0.0656	15.2403	1.2700	0.7874
73	20.2778	0.0203	49.3151	0.4932	2.0278	45.3593	66.5269	0.0665	15.0315	1.2526	0.7983
74	20.5556	0.0206	48.6486	0.4865	2.0556	45.9806	67.4383	0.0674	14.8284	1.2357	0.8093
75	20.8333	0.0208	48.0000	0.4800	2.0833	46.6020	68.3496	0.0683	14.6307	1.2192	0.8202
76	21.1111	0.0211	47.3684	0.4737	2.1111	47.2234	69.2609	0.0693	14.4382	1.2032	0.8311
77	21.3889	0.0214	46.7532	0.4675	2.1389	47.8447	70.1723	0.0702	14.2506	1.1876	0.8421
78	21.6667	0.0217	46.1538	0.4615	2.1667	48.4661	71.0836	0.0711	14.0679	1.1723	0.8530
79	21.9444	0.0219	45.5696	0.4557	2.1944	49.0874	71.9949	0.0720	13.8899	1.1575	0.8639
80	22.2222	0.0222	45.0000	0.4500	2.2222	49.7088	72.9062	0.0729	13.7162	1.1430	0.8749
81	22.5000	0.0225	44.4444	0.4444	2.2500	50.3302	73.8176	0.0738	13.5469	1.1289	0.8858
82	22.7778	0.0228	43.9024	0.4390	2.2778	50.9515	74.7289	0.0747	13.3817	1.1151	0.8967
83	23.0556	0.0231	43.3735	0.4337	2.3056	51.5729	75.6402	0.0756	13.2205	1.1017	0.9077
84	23.3333	0.0233	42.8571	0.4286	2.3333	52.1942	76.5516	0.0766	13.0631	1.0886	0.9186
85	23.6111	0.0236	42.3529	0.4235	2.3611	52.8156	77.4629	0.0775	12.9094	1.0758	0.9296
86	23.8889	0.0239	41.8605	0.4186	2.3889	53.4370	78.3742	0.0784	12.7593	1.0633	0.9405
87	24.1667	0.0242	41.3793	0.4138	2.4167	54.0583	79.2855	0.0793	12.6126	1.0511	0.9514
88	24.4444	0.0244	40.9091	0.4091	2.4444	54.6797	80.1969	0.0802	12.4693	1.0391	0.9624
89	24.7222	0.0247	40.4494	0.4045	2.4722	55.3010	81.1082	0.0811	12.3292	1.0274	0.9733
90	25.0000	0.0250	40.0000	0.4000	2.5000	55.9224	82.0195	0.0820	12.1922	1.0160	0.9842
91	25.2778	0.0253	39.5604	0.3956	2.5278	56.5438	82.9308	0.0829	12.0582	1.0049	0.9952
92	25.5556	0.0256	39.1304	0.3913	2.5556	57.1651	83.8422	0.0838	11.9272	0.9939	1.0061
93	25.8333	0.0258	38.7097	0.3871	2.5833	57.7865	84.7535	0.0848	11.7989	0.9832	1.0170
94	26.1111	0.0261	38.2979	0.3830	2.6111	58.4078	85.6648	0.0857	11.6734	0.9728	1.0280
95	26.3889	0.0264	37.8947	0.3789	2.6389	59.0292	86.5762	0.0866	11.5505	0.9625	1.0389
96	26.6667	0.0267	37.5000	0.3750	2.6667	59.6506	87.4875	0.0875	11.4302	0.9525	1.0498
97	26.9444	0.0269	37.1134	0.3711	2.6944	60.2719	88.3988	0.0884	11.3124	0.9427	1.0608
98	27.2222	0.0272	36.7347	0.3673	2.7222	60.8933	89.3101	0.0893	11.1969	0.9331	1.0717
99	27.5000	0.0275	36.3636	0.3636	2.7500	61.5146	90.2215	0.0902	11.0838	0.9237	1.0827
100	27.7778	0.0278	36.0000	0.3600	2.7778	62.1360	91.1328	0.0911	10.9730	0.9144	1.0936

APPENDIX B

Scan Tools, Scanners, Bus Interfaces, and Manufacturer Contacts

Manufacturer/Contact	Model	Vehicles	Base Price	Comments
ACCUTEST sofa.dartnet.co.uk	J1850 Network Analysis Tool (DG-JNAT-B) J1850 & OBD2 Compliance Tester (DG-JNAT-C) J1850 & OBD2 Flight Recorder & Compliance Tester (DG-JNAT-D)	GM, Ford, or Chrysler		Multiple tools and testers for diagnostics, monitoring, and troubleshooting of multiplexed automation and automotive communication networks.
Actron Manufacturing Co. 9999 Walford Ave. Cleveland, OH 44102 216-651-9200 www.actron.com	Kal Equip OBD-II System Tester 9615			Basic Scanner
Actron Manufacturing Co. 9999 Walford Ave. Cleveland, OH 44102 216-651-9200 www.actron.com	KAL Equip Scan—II CP9600	OBD-II, RS-232		Basic Scanner
Advance Electronic Diagnostics	Vehicle Communication System (VCS)	Ford, Chrysler, and GM Models, year 1996 and beyond that are J1850 compliant. VCS Driver for VLTC2W is for GM only.	$350	PC to vehicle communications. J1850/ALDL UART PCMCIA Card $1200 VCS Driver for Lab View $350 Vital Signs II Software Package $450 VCS Driver for VLTC2W-DLL (GM only)
Advanced Vehicle Technologies, Inc. (AVT) 1509 Manor View Road Davidsonville, MD 21035 410-798-4038 Michael Riley	AVT-716—Triple Interface (J1850 VPW, PWM and ISO 9141)	Any OBD-II equipped		Hardware package allows a PC terminal (with appropriate software) to communicate with a vehicle data network and capture data bus message traffic. Unit may also be used to simulate messages to connected ECUs and check for ECU/actuator responses.
Assenmacher Specialty Tools (AST) Mike Assenmacher 6440 Odell Place Boulder, CO 80301 303-530-2424 *Supplier* Technic Tool Supply Unit J, 2057 Goodyear Ave. Ventura, CA 93003 1-800-637-8738 www.technictool.com	5700 Retriever Scan Tool	VW/Audi, Seat, Skoda, BMW, Mercedes-Benz, Saab, Volvo, OBD II	$627 (thru 1999)	VW/Audi, Seat Skoda Cartridge: $811 C Retriever Cartridge for BMW 88-99: $1407 Volvo Cartridge 94 - 98: $998 OBD II Cartridge Kit for ISO Standard Vehicles: $583.96 OBD II Cartridge Only: $385 Mercedes Cartridge Kit: $940 Mercedes Cartridge Only: $890 OBD II Cable: $180
BAUM Tools Unlimited P.O. Box 5867 Sarasota, FL 34177-5867 1-800-848-6657 www.baumtools.com	CS2000 Live Data Scanner	88–99 Mercedes, BMW, VW/Audi, Volvo, OBD II-ISO9141-2		Displays info in OE format.
B & B Electronics 707 Dayton Road P.O. Box 1040 Ottawa, IL 61350 815-433-5100 Voice 815-433-5105 Fax *www.autotap.com*	AutoTap AT12	1996 and above, GM and Ford cars and light trucks	$390	Communicate with vehicle via a PC.

Manufacturer/Contact	Model	Vehicles	Base Price	Comments
CODA Products 97 Denison Street Hamilton, NSW 2303 Australia +61 (2) 4962 2576 +61 (2) 4969 3875 sales@coda.com.au orders@coda.com.au	Data Scanner, Harness 1	Australian and Import Vehicles		Coda Data Scanner Base Kit, EB to EF Falcon, Fairlane, LTD Update Lead, Mitsubishi TP to TS Magna, Lancer, Triton, Pajero, Star Wagon, L300, Nimbus, Galant Update Lead, Holden Isuzu Update Lead for four cylinder Rodeo and Jackaroo, Ford/Mazda Update Lead for late model Laser, Capri, Probe and Telstar as well as 121, 323, Astina, 626, 929 and all late Mazda, Coda VR Interface (3 versions), VS Commodore Software Update
Dearborn Group, Inc. 27007 Hills Tech Court Farmington Hills, MI 48331 248-488-2080 Voice 248-488-2082 Fax www.dgtech.com	Gryphon			High-speed interface for diagnostics, monitoring, and troubleshooting of multiplexed automation and automotive communication networks.
EASE Diagnostics New Milford, PA 570-465-9062 Voice 570-465-9061 Fax www.obdz.com	ST2 Scan Tool Deluxe	All vehicles OBD-II generic		Chassis options available. Laptop PC display and interface
General Motors Service Operations www.gmde.com/news	Central Server and LAN (Local Area Network)	GM		Service information in a user-friendly format—a Web-based format. Will link dealership operations.
Hickok Incorporated 10514 Dupont Avenue Cleveland, OH 44108 800-342-5080 Voice 216-541-8060 Voice www.hickok-inc.com	New Generation STAR Tester (NGS Tester) Version 14.0	Ford, Mazda		OBD II compatible
Highlander Vehicle Networking Products www.highlandertech.com/technologies	VNIC/S Controller			—EZ-Link family of software for vehicle communication —Single-board computers based on Intel 80C196 and ×86- based embedded processors —Hardware/software consulting for in-vehicle networks
Injectoclean Diagnostic Equipment www.injectoclean.com	CJScan	GM, Ford, Chrysler, most Asian and European vehicles, and OBD-II. Volswagen 1993–98		Basic Scanner. Also, has optional kit that allows connection to a PC.
Kontron Embedded Computers Eching/Munchen Germany +49 8165 77-666 Voice +49 8165 77-219 Fax www.kontron.com sales@kontron.com	IP Lite			—Processor: Pentium 233 Mhz, Pentium II, 300 Mhz —L2 Cache: 512 kB Pipelined Burst —Ram: 64, 128 MB (PW5); up to 256 MP (PII)
Mobile Data Systems 33228 W. 12 Mile Road, Suite 352 Farmington Hills, MI 48334 248-344-8029 Voice 248-851-7305 Fax www.mobiledatasystems.com	J Cable	J1850 VPW (Chrysler), PWM (Ford), VPW (GM), and GM UART, ISO 9141 K Lines		This cable communicates with engine, transmission, and body controllers via an SAE J1962 diagnostic connector.
Molex Incorporated 2222 Wellington Court Lisle, IL 60532-1682 800-78MOLEX Voice 630-968-8356 Fax amerinfo@molex.com	OBD-II connector supplier.			4.00 mm (0.157 in.) wire-to-wire receptable housing, flange mount
MPSI 800-639-6774 Voice www.mpsilink.com	Multi-Protocol Cartridge (MPC)	All foreign/domestic OBD II vehicles		

Manufacturer/Contact	Model	Vehicles	Base Price	Comments
NSI www.nsi.fr/products	Diagnostic Tool Set (DTS)	BMW DS2, Mercedes Benz FB, VW/Audi VW 1281, Ford ISO 9141		Diagnostic Tester Process Viewer Test Batch Executor
North Star Laboratory 754 White Pine Road Sanatoga, PA 19464 610-326-8425 Voice www.northstarlabs.com	OBD-II Protocol	Automobiles and light trucks		
Rinda Technologies 4563 N. Elston Ave Chicago, IL 60630 773-736-6633	Diacom and Diacom Plus	GM and Chrysler cars and light trucks	Handheld scan tools	Handheld scan tools
Smart Engineering Tools, Inc. Representative: Sigmund Shvimer Smart Engineering Tools, Inc. 100 North Pond Drive, Suite D Walled Lake, MI 48390 248-669-7262 Voice 248-669-8159 Fax www.smtools.com info@smtools.com	Netway FP1 CAN, J1850, UART	Any OBD-II equipped		Software and hardware package allows a PC terminal to communicate with a vehicle data network and capture data bus message traffic. Unit may also be used to simulate messages to connected ECUs and check for ECU/actuator responses.
Silicon Engines 2101 Oxford Road Des Plaines, IL 60018 847-803-6860 Voice 847-803-6870 Fax www.siliconengines-ltd.com	ISO-9141	Concept cars, prototypes, and low-volume vehicles		
Snap-On 3550 Snell Avenue San Jose, CA 95136-9968 800-424-7226 www.snapondiagnostics.com	MT2500 Scantool MT2400 Vantage MT2700 DIS/kv Ignition Probe	Acura, Chrysler, Ford, GM, Honda, Hyundai, Infiniti, Isuzu, Lexus, Mazda, Mitsubishi, Nissan, Subaru, and Toyota		Handheld scan tools Includes aerial print function. Includes emissions and chassis functions.
SPX Corporation 28635 Mound Road Warren, MI 48092-3499 800-328-6657 www.adspx.com	MindReader OBD II	Ford, Chrysler, GM, Asian		1981–1999+ Allen Testproducts, Bear Automotive and OTC products.
SPX Kent-Moore SPX Corporation 28635 Mound Road Warren, MI 48092-3499 800-328-6657 Voice 800-578-7375 Fax	Pro-Link Plus	Detroit Deisel DDEC III and IV, Mack Trucks VMAC III, Navistar NAVPAK, Eaton, Bendix. Meritor WABCO ABS, Caterpillar, Allison		
SPX OTC Owatonna, MN 55060-1171 800-533-6127 Voice 800-955-8329 Fax	OTC 4000 enhanced			Multi System Vehicle Scan Tool
Vetronix 2030 Alameda Padre Serra Santa Barbara, CA 93103 800-321-4889 www.vetronix.com *Sales/Marketing Contact* Jason Alexander	Alliance Diagnostic System	GM, Ford, Chrysler, Asian Imports		
Vetronix 2030 Alameda Padre Serra Santa Barbara, CA 93103 800-321-4889 www.vetronix.com *Sales/Marketing Contact* Jason Alexander	Mastertech	GM, Ford, Chrysler, Asian		

Manufacturer/Contact	Model	Vehicles	Base Price	Comments
Vetronix 2030 Alameda Padre Serra Santa Barbara, CA 93103 800-321-4889 www.vetronix.com *Sales/Marketing Contact* Jason Alexander	Tech 1A	GM, Ford, Toyota, Lexus		ABS: Delco Moraine, Bosch, Teves, Kelsey-Hayes
Vetronix 2030 Alameda Padre Serra Santa Barbara, CA 93103 800-321-4889 www.vetronix.com *Sales/Marketing Contact* James Kerr	CDR	GM		The CDR is the first publicly available scanner to provide a translation of the air bag ECU EEPROM hexadecimal data. However, not all hexadecimal data is translated. Translated data includes seat belt usage, cumulative Delta V, and four pre-impact parameter values captured at −5, −4, −3, −2, and −1 s before impact (speed, throttle %, brake apply, and engine RPM). Not all capabilities are available for all vehicle models.

NOTES:

1. The author has endeavored to include all known and pertinent scan tools in this Appendix. No attempt to grade or qualify any of these tools is included or intended. If any scan tools have been left out, such omissions are entirely inadvertent and not intended to imply any value judgment.
2. The scan tools and/or network monitors mentioned above have varying freeze frame data retrieval capabilities. The reader should consult with specific scan tool manufacturers to verify freeze frame data capabilities for any specific system.

APPENDIX C

Government Standards and Regulations (CARB, DOT/NHTSA, EPA)

Regulation #	Regulation Title	Reference Source
40 CFR Parts 9, 85, and 86 [AMS-FRL-5938-8] RIN 2060-AF75	Control of Air Pollution From New Motor Vehicles and New Motor Vehicle Engines: State Commitments to National Low Emission Vehicle Program AGENCY: Environmental Protection Agency (EPA). ACTION: Final Rule.	Federal Register: 7 Jan. 1998 (Vol. 63, No. 4) [Rules and Regulations] pp. 925–987
40 CFR Part 86 [FRL-5558-3] RIN 2060-AE27	Final Regulations for Revisions to the Federal Test Procedure for Emissions From Motor Vehicles AGENCY: Environmental Protection Agency (EPA). ACTION: Final rulemaking (FRM).	Federal Register: 22 Oct.1996 (Vol. 61, No. 205) [Rules and Regulations] pp. 54851–54906
40 CFR Parts 9 and 86 [AMS-FRL-5908-8] RIN 2060-AF76	Control of Emissions of Air Pollution From Highway Heavy-Duty Engines AGENCY: Environmental Protection Agency (EPA). ACTION: Final rule.	Federal Register: 21 Oct. 1997 (Vol. 62, No. 203)] [Rules and Regulations] pp. 54693–54730
40 CFR Parts 85 and 86 [AMS-FRL-5823-7] RIN 2060-AF75	Control of Air Pollution From New Motor Vehicles and New Motor Vehicle Engines: Voluntary Standards for Light-Duty Vehicles AGENCY: Environmental Protection Agency (EPA). ACTION: Final rule.	Federal Register: 6 June 1997 (Vol. 62, No. 109) [Rules and Regulations] pp. 31191–31270
40 CFR Parts 9 and 86 [FRL-5881-3]	Direct Final Rule Amending the Test Procedures for Heavy-Duty Engines, and Light-Duty Vehicles and Trucks and the Amending of Emission Standard Provisions for Gaseous Fueled Vehicles and Engines AGENCY: Environmental Protection Agency (EPA). ACTION: Direct Final Rule.	Federal Register: 5 Sep. 1997 (Vol. 62, No. 172) [Rules and Regulations] pp. 47113–47136
40 CFR Parts 9 and 86 [AMS-FRL-5268-1] RIN 2060-AE93	Control of Air Pollution From New Motor Vehicles and New Motor Vehicle Engines; Regulations Requiring Availability of Information for Use of On-Board Diagnostic Systems and Emission-Related Repairs on 1994 and later Model Year Light-Duty Vehicles and Light-Duty Trucks AGENCY: Environmental Protection Agency (EPA). ACTION: Final Rule.	Federal Register: 9 Aug. 1995 (Vol. 60, No. 153) [Rules and Regulations] pp. 40474–40498
40 CFR Parts 51 and 85 [FRL-5543-7] RIN 2060-AE19	Inspection/Maintenance (I/M) Program Requirement—On-Board Diagnostic Checks; Final rule AGENCY: Environmental Protection Agency. ACTION: Final rule.	Federal Register: 6 Aug. 1996 (Vol. 61, No. 152) [Rules and Regulations] pp. 40939–40948
40 CFR Part 86 [FRL-6196-4]	Control of Air Pollution From Motor Vehicles and New Motor Vehicle Engines; Modification of Federal On-board Diagnostic Regulations for Light-Duty Vehicles and Light-Duty Trucks; Extension of Acceptance of California OBD II Requirements AGENCY: Environmental Protection Agency. ACTION: Final Rule.	Federal Register: 22 Dec. 1998 (Vol. 63, No. 245) [Rules and Regulations] pp. 70681–70697
40 CFR Part 86 [AMS-FRL-5602-3] RIN 2060-AC65	Control of Air Polution From New Motor Vehicles and New Motor Vehicle Engines: Regulations Requiring On-Board Diagnostic (OBD) Systems—Acceptance of Revised California OBD II Requirements AGENCY: Environmental Protection Agency (EPA). ACTION: Final Rule.	[Federal Register: August 30, 1996 (Volume 61, Number 170)] [Rules and Regulations] [Page 45898–45903]
40 CFR Part 86 [AMS-FRL-5225-7] RIN 2060-AC65	Control of Air Pollution From New Motor Vehicles and New Motor Vehicle Engines: Regulations Requiring On-Board Diagnostic (OBD) Systems—Regulations Allowing Optional Compliance with California OBD II Requirements as Satisfying Federal OBD AGENCY: Environmental Protection Agency (EPA). ACTION: Final Rule.	[Federal Register: July 25, 1995 (Volume 60, Number 142)] [Rules and Regulations] [Page 37945]
CARB Mail Outs: Code of Regulation, Title 13	1968.1, Malfunction and Diagnostic System 21 May1993, 1994 and Subsequent Model-Year Passenger Cars, Light Duty Trucks, and Medium Duty Vehicles and Engines	

Document Sources

SAE publications are available from SAE, 400 Commonwealth Drive, Warrendale, PA, 15096-0001, ph. 724-776-4841.
ISO documents are available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.
EPA documents are available in the Federal Register. Contact: U.S. Environmental Protection Agency, 2565 Plymouth Road, Ann Arbor, MI, 48105, ph. 313-668-4400 or http://www.epa.gov/fedrgstr/EPA-AIR/.
Bosch documents are available from Robert Bosch GmBh, Postfach 50, D7000, Stuttgart, Germany.
CARB = California Air Resources Board, 2020 L Street, Sacramento, CA, 95814, ph. 916-322-2990.

APPENDIX D

Industry Standards and Specifications (SAE, ASTM, ISO, etc.)

Standard #	Standard/Specification Name	Current Revision level
Bosch	CAN Specification 2.0	September 1991
ISO 14229	Road Vehicles, Diagnostic Systems, Diagnostic Services Specification	
ISO/DIS 14230-1	Road Vehicles, Diagnostic Systems, Keyword Protocol 2000—Part 1: Physical Layer	
ISO/DIS 14230-2	Road Vehicles, Diagnostic Systems, Keyword Protocol 2000—Part 2: Data Link Layer	
ISO/DIS 14230-3	Road Vehicles, Diagnostic Systems, Keyword Protocol 2000—Part 3: Application Layer	
ISO/DIS 14230-4	Road Vehicles, Diagnostic Systems, Keyword Protocol 2000—Part 4: Requirements for Emission Related Systems	
ISO 9141-2:1994(E)	Road Vehicles, Diagnostic Systems, CARB Requirements for Interchange of Information, ISO/TC 22/SC 3/WG 1 -N 425 E/REV	
ISO/IEC 9646	Information Technology, Open Systems Interconnection, Conformance Testing Methodology and Framework	
ISO 15031-3	Diagnostic Connector and Related Electrical Circuits: Specification and Use	
ISO 8092-3	Road Vehicles, Flat, Quick Connection Terminations	
ISO 11898		
SAE J211	Instrumentation for Impact Test	October 1988
SAE J670e	Vehicle Dynamics Terminology	July 1976
SAE J1113/1	Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components—60 Hz to 18 GHz	July 1995
SAE J1113/2	Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components—Conducted Immunity, 30 Hz to 250 kHz	September 1996
SAE J1113/3	Conducted Immunity, 250 kHz to 500 MHz Direct Injection of Radio Frequency (RF) Power	November 1995
SAE J1113/4	Innunity to Radiated Electromagnetic Fields—Bulk Current Injection (BCI) Method	February 98
SAE J1113/11	Immunity to Conducted Transients on Power Leads	June 1995
SAE J1113/12	Electrical Interference by Conduction and Coupling—Coupling Clamp	December 1994
SAE J1113/13	Electromagnetic Compatibility Measurement Procedure for Vehicle Components—Immunity to Static Discharge	October 1996
SAE J1113/21	Electromagnetic Compatibility Measurement Procedure for Vehicle Components—Immunity to Radiated Electromagnetic Fields, 10 kHz to 18 Ghz, Absorber Lined Chamber	January 1998
SAE J1113/22	Electromagnetic Compatibility Measurement Procedure for Vehicle Components—Immunity to Magnetic Fields From Power Lines	October 1996
SAE J1113/23	Electromagnetic Compatibility Measurement Procedure— Immunity to Radiated Electromagnetic Fields, 10 kHz to 200 MHz, Strip Line Method	September 1995
SAE J1113/41	Electromagnetic Susceptibility Measurements Procedures for Vehicle Components (60 Hz to 18 GHz)	July 1995
SAE J1211	A Recommended Environmental Procedure for Electronic Equipment Design	November 1978
SAE J1213-1	Glossary of Vehicle Networks for Multiplexing and Data Communications	September 1997
SAE J1547	Electromagnetic Susceptibility Measurement Procedures for Common Mode Injection	October 1988
SAE J1587	Joint SAE/TMC Electronic Data Interchange Between Microcomputer Systems in Heavy-Duty Vehicles	March 1996
SAE J1699	Verification of OBD-II Related	January 1998
SAE J1708	Serial Data Communications Between Microcomputer Systems in Heavy-Duty Vehicle Applications	October 1993
SAE J1850	Class B Data Communications Network Interface	March 1998
SAE J1879	General Qualification and Production Acceptance Criteria for Integratred Circuits in Automotive Applications	October 1998

Standard #	Standard/Specification Name	Current Revision level
SAE J1930	Electrical/Electronic Systems Diagnostic Terms Definitions, Abbreviations & Acronyms	May 1998
SAE J1939-11	Recommended Practice for Serial Control and Communications Vehicle Network—Physical Layer—250 K bits/sec, Shielded Twisted Pair	December 1994
SAE J1939-21	Recommended Practice for Serial Control and Communications Vehicle Network—Data Link Layer	July 1994
SAE J1939-31	Recommended Practice for Serial Control and Communications Vehicle Network—Network Layer	December 1997
SAE J1939-71	Recommended Practice for Serial Control and Communications Vehicle Network—Vehicle Application Layer	May 1996
SAE J1939-81	Recommended Practice for Serial Control and Communications Vehicle Network—Network Management	July 1997
SAE J1962	Diagnostic Connector	February 1998
SAE J1978	OBD-II Scan Tool	February 1998
SAE J1979	E/E Diagnostic Test Modes	September 1997
SAE J2008	Recommended Organization of Vehicle Service Information	
SAE J2012	Recommended Message Format and Messages for Diagnostic Trouble Codes	July 1996
SAE J2178	Class B Data Communications Network Messages	January 1995
SAE J2178-1	Class B Data Communications Network Messages: Detailed Header Formats and Physical Address Assignments	January 1995
SAE J2178-2	Class B Data Communications Network Messages—Part 2—Data Parameter Definitions	May 1997
SAE J2178-3	Class B Data Communications Network Messages—Part 3—Frame IDS for Single-Byte Forms of Headers	June 1998
SAE J2178-4	Class B Data Communications Network Messages—Part 4—Message Definitions for Three Byte Headers	February 1995
SAE J2186	E/E Data Link Security	October 1996
SAE J2190	Enhanced E/E Diagnostic Test Modes	June 1993
SAE J2201	Universal Interface for OBD-II Scan	June 1993
SAE J2205	Expanded Diagnostic Protocol for OBD-II Scan Tools	December 1995
SAE J2223-3	Connections for On-board Road Vehicle Electrical Wiring Harnesses, Part 3, Multipole Connectors, Flat Blade	February 1994
SAE J2284	High Speed CAN (HSC) for Passenger Vehicle Applications	February 1999

Document Sources

SAE publications are available from SAE, 400 Commonwealth Drive, Warrendale, PA, 15096-0001, ph. 724-776-4841.
ISO documents are available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.
EPA documents are available in the Federal Register. Contact: U.S. Environmental Protection Agency, 2565 Plymouth Road, Ann Arbor, MI, 48105, ph. 313-668-4400 or http://www.epa.gov/fedrgstr/EPA-AIR/.
Bosch documents are available from Robert Bosch GmBh, Postfach 50, D7000, Stuttgart, Germany.
CARB = California Air Resources Board, 2020 L Street, Sacramento, CA, 95814, ph. 916-322-2990.

APPENDIX E.1

A Comparison of Commercial Aircraft Digital Flight Data Recorder Requirements (DFDR) versus Passenger and Truck Land Vehicle ECU EEPROM or Flash Memory Data.

#	Commercial Aircraft Digital Flight Data Recorder Data Parameters (1)						Land Vehicle Data (2)	
	DFDR Parameter	No FDAU, mfg. Before 10/11/91	w/FDAU, Before 10/11/91	Digital Data and ARINC 717 DFDAU, mfg. Before 10/11/91	Mfg. After 10/11/91	Mfg. After 8/18/00	Most Comparable Land Vehicle Data Parameter (in Various Vehicles)	Typical Source ECU
1	Time	x	x	x	x	x	Ignition Cycle	SRS, PCM
2	Pressure Altitude	x	x	x	x	x		
3	Indicated Airspeed	x	x	x	x	x	Vehicle Speed	PCM,BCM
4	Heading—primary flight crew reference (if selectable, record discrete, true, or magnetic)	x	x	x	x	x		
5	Normal Acceleration (Vertical)	x	x	x	x	x		
6	Pitch Attitude	x	x	x	x	x		
7	Roll Attitude	x	x	x	x	x		
8	Manual radio transmitter keying or CVR/DFDR synchronization reference	x	x	x	x	x		
9	Thrust/power of each engine—primary flight crew reference	x	x	x	x	x	Engine Power Level	PCM
10	Autopilot engagement status	x	x	x	x	x	Cruise Control Status	PCM
11	Longitudinal Acceleration	x	x	x	x	x	Saved as a_{sample} or $\Delta V_{sample} = \langle a_{sample} \rangle t_{sample}$	SRS
12	Pitch control input	x	x	x	x	x		
13	Lateral control input	x	x	x	x	x		
14	Rudder pedal input	x	x	x	x	x		
15	Primary pitch control surface position	x	x	x	x	x		
16	Primary lateral control surface position	x	x	x	x	x		
17	Primary Yaw control surface position	x	x	x	x	x		
18	Lateral acceleration	x	x	x	x	x		
19	Pitch trim surface position or (82), if currently recorded		x	x	x	x		
20	Trailing edge flap or cockpit flap control selection (except when (85) applies)		x	x	x	x		
21	Leading edge flap or cockpit flap control selection (except when (86) applies)		x	x	x	x		
22	Each thrust reverser position (or equivalent for propeller airplane)		x	x	x	x		
23	Ground spoiler position or speed brake selection (except when (87) applies)				x	x		
24	Outside or total air temperature				x	x		

#	Commercial Aircraft Digital Flight Data Recorder Data Parameters (1)						Land Vehicle Data (2)	
	DFDR Parameter	No FDAU, mfg. Before 10/11/91	w/FDAU, Before 10/11/91	Digital Data and ARINC 717 DFDAU, mfg. Before 10/11/91	Mfg. After 10/11/91	Mfg. After 8/18/00	Most Comparable Land Vehicle Data Parameter (in Various Vehicles)	Typical Source ECU
25	Automatic Flight Control System (AFCS) modes and engagement status, including autothrottle				x	x		
26	Radio altitude (when information source installed)				x	x		
27	Localizer deviation, MLS Azimuth				x	x		
28	Glideslope deviation, MLS Elevation				x	x		
29	Marker beacon passage				x	x		
30	Master warning				x	x	MIL Status SRS, ABS, PCM	SRS, ABS, PCM
31	Air/ground sensor (primary airplane system reference nose or main gear)				x	x		
32	Angle of attack (when information source installed)				x	x		
33	Hydraulic pressure low (each system)				x	x		
34	Ground speed (when information source installed)				x	x	Vehicle Speed	ABS
35	Ground proximity warning system					x	Other vehicle proximity	BCM
36	Landing gear position or landing gear cockpit control selection					x		
37	Drift angle (when information source installed)					x		
38	Wind speed and direction (when information source installed)					x		
39	Latitude and longitude (when equipped)					x	GPS Data, when equipped	BCM
40	Stick shaker/pusher (when equipped)					x		
41	Windshear (when equipped)					x		
42	Throttle/power lever position					x	Accel % or Throttle %	PCM
43	Additional engine parameters (Appendix M)					x		
44	Traffic alert and collision avoidance system					x		
45	DME 1 and 2 distances					x		
46	Nav 1 and 2 selected frequency					x		
47	Selected barometric setting (when information source installed)					x		
48	Selected altitude (when equipped)					x		
49	Selected speed (when information source installed)					x	Vehicle Speed (VSS) Wheel Speeds (WSS)	PCM ABS
50	Selected mach (when information source installed)					x		

#	Commercial Aircraft Digital Flight Data Recorder Data Parameters (1)						Land Vehicle Data (2)	
	DFDR Parameter	No FDAU, mfg. Before 10/11/91	w/FDAU, Before 10/11/91	Digital Data and ARINC 717 DFDAU, mfg. Before 10/11/91	Mfg. After 10/11/91	Mfg. After 8/18/00	Most Comparable Land Vehicle Data Parameter (in Various Vehicles)	Typical Source ECU
51	Selected vertical speed (when information source installed)					x		
52	Selected heading (when information source installed)					x		
53	Selected flight path (when information source installed)					x		
54	Selected decision height (when information source installed)					x		
55	EFIS display format					x		
56	Multi-function/engine/alerts display format					x		
57	Thrust command (when information source installed)					x		
58	Thrust target (when information source installed)							
59	Fuel quantity in CG trim tank (when information source installed)							
60	Primary Navigation System Reference							
61	Icing (when information source installed)							
62	Engine warning each engine vibration (when information source installed)							
63	Engine warning each engine over temp (when information source installed)							
64	Engine warning each engine oil pressure low (when information source installed)							
65	Engine warning each engine over speed (when information source installed)							
66	Yaw trim surface position							
67	Roll trim surface position							
68	Brake pressure (selected system)						Brake Boost Vacuum Warning	PCM
69	Brake pedal application (left and right)						Brake Apply Status	ABS, PCM
70	Yaw or sideslip angle (when information source installed)							
71	Engine bleed valve position (when information source installed)							
72	De-icing or anti-icing system selection (when information source installed)							
73	Computed center of gravity (when information source installed)							
74	AC electrical bus status							
75	DC electrical bus status							

#	Commercial Aircraft Digital Flight Data Recorder Data Parameters (1)						Land Vehicle Data (2)	
	DFDR Parameter	No FDAU, mfg. Before 10/11/91	w/FDAU, Before 10/11/91	Digital Data and ARINC 717 DFDAU, mfg. Before 10/11/91	Mfg. After 10/11/91	Mfg. After 8/18/00	Most Comparable Land Vehicle Data Parameter (in Various Vehicles)	Typical Source ECU
76	APU bleed valve position (when installed)							
77	Hydraulic pressure (each system)							
78	Loss of cabin pressure							
79	Computer failure							
80	Heads-up display (when installed)							
81	Para-visual display (when installed)							
82	Cockpit trim control input position—pitch							
83	Cockpit trim control input position—roll							
84	Cockpit trim control input position—yaw							
85	Trailing edge flap and cockpit flap control position							
86	Leading edge flap and cockpit flap control position							
87	Ground spoiler position and speed brake selection							
88	All cockpit flight control input forces (control wheel, control column, rudder pedal)							

(1) Recorded continuously in flight operation.
(2) Usually only available when an "event" has occurred. Events can be the storage of a DTC or a vehicle impact.

APPENDIX E.2

Parameters in SRS and ABS ECUs

SRS ECU Parameters:

1. Crash/Near Crash History Fault Codes
2. Crash/Near Crash Ignition Cycle Fault Codes
3. Crash/Near Crash Active Fault Codes
4. Global History Fault Codes
5. Crash/Near Crash Internal ECU Fault Codes
6. Global Internal ECU Fault Codes
7. Total Ignition Cycle Count
8. Crash/Near Crash Ignition Cycle Count
9. Crash/Near Crash Warning Lamp Status
10. Crash/Near Crash Delta V Data
11. Crash/Near Crash Algorithm Enable Status
12. Crash/Near Crash Jerk Threshold Exceeded Status
13. Crash/Near Crash Energy Boundary Threshold Exceeded Status
14. Crash/Near Crash Velocity Boundary Threshold Exceeded Status
15. Crash/Near Crash Driver Seatbelt Status
16. Crash/Near Crash Passenger Seatbelt Status
17. Time between Near Crash and Crash (each crash event)
18. Crash Algorithm Enable to Overlap or Arming Sensor Closure Time
19. Crash Algorithm Enable to Crash Time
20. Crash Algorithm Enable to Discriminating Sensor Closure Time
21. Near Crash Algorithm Enable to Max Delta V
22. Near Crash Max Delta V
23. Vehicle Speed Before Algorithm Enable
24. Engine Speed Before Algorithm Enable
25. Throttle Position Before Algorithm Enable
26. Brake Switch Status Before Algorithm Enable
27. Seat Occupancy Detection/Discrimination
28. Side Air Bag Data
29. Passenger Air Bag On/Off Switch State

ABS ECU Parameters:

1. Wheel Speed
2. Active Faults
3. History Faults
4. Brake Switch Status
5. Number of ABS Occurrences
6. Number of Ignition Cycles Before First Fault
7. Number of Ignition Cycles After First Fault
8. Warning Lamp Status
9. Vehicle Speed
10. Pump Motor
11. Valve Relay
12. Engine Torque
13. Solenoids
14. ABS State
15. Engine Speed

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