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An Examination of Sudden Acceleration

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16. Abstract

This report describes the results of a study to identify and evaluate factors which could potentially cause or contribute to the occurrence of "Sudden Acceleration Incidents" (SAI). SAI are defined in this report as unintended, unexpected, high-power accelerations from a stationary position or a very low initial speed accompanied by an apparent loss of braking effectiveness. Ten vehicles with above-average SAI complaint rates were selected for particular scrutiny.

In the course of conducting this study, the Transportation Systems Center: (1) convened a panel of independent experts in various disciplines related to SAI concerns to review this material with TSC; (2) collected the relevant literature and case documentation on the vehicles; (3) studied the fuel-systems, braking systems, and driving controls of the vehicles; (4) performed appropriate tests and experiments or arranged for their conduct at NHTSA's Vehicle Research and Test Center (VRTC); and (5) documented the findings and conclusions, as noted below.

(1) No malfunctions were found which could cause high engine power without opening the throttle. (2) Certain malfunctions were identified which could cause throttle opening or sticking, but these would be readily detectable in post-SAI investigation. (3) Other malfunctions were found that could cause modest increases in engine power, some of which would be difficult to detect in an investigation. These malfunctions could not directly cause an SAI but might startle the driver into a pedal misapplication (depression of the accelerator instead of, or in addition to, the brake pedal). (4) Vehicle pedal design features were identified which might increase the probability of a pedal misapplication. All the vehicles with high SAI-compliant rates which were measured were found to possess pedal designs conducive to pedal misapplication.

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Preface

This report was prepared by the U.S. Department of Transportation, Transportation Systems Center (TSC) for the National Highway Traffic Safety Administration, Office of Defects Investigation. The work was performed by TSC's Operator Performance and Safety Analysis Division.

The authors are also indebted to the numerous vehicle owners who consented to be interviewed about their experiences with sudden acceleration, some of whom also provided vehicles for testing. The cooperation of vehicle manufacturers and dealers who supplied extensive technical documentation, parts and test vehicles is gratefully acknowledged. Finally, the assistance of public-interest safety groups in directing drivers involved in sudden-acceleration incidents to contact TSC as soon as possible after an accident was most helpful.

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Background

This report describes the results of a study to identify and evaluate factors which could potentially cause or contribute to the occurrence of "Sudden Acceleration Incidents" (SAI). For the purposes of this report SAI are defined as unintended, unexpected, high-power accelerations from a stationary position or a very low initial speed accompanied by an apparent loss of braking effectiveness. The typical SAI scenario, as abstracted from National Highway Traffic Safety Administration's (NHTSA) complaint files, begins at the moment of shifting to "Drive" or "Reverse" from "Park." Most of the reported SAI terminate in some form of collision with another vehicle or a fixed object and include driver statements concerning lack of braking effectiveness. Incidents which are made known to NHTSA are "Reported Sudden Acceleration Incidents," hereinafter abbreviated as RSAI. NHTSA's files include thousands of these reports, including almost every make of vehicle, virtually all of which occurred in vehicles with automatic transmissions.

The factors which cause and/or contribute to the occurrence of SAI have been a matter of considerable public controversy and media attention. To help resolve this controversy and to explore topics not fully investigated previously, the Administrator of NHTSA ordered an independent review of the current state of understanding of the SAI phenomenon in October, 1987. Because of the knowledge and experience it gained while assisting NHTSA with the Audi 5000 investigation, the Transportation Systems Center (TSC) was chosen to conduct this review. Ten make/model/year vehicles with above-average SA complaint rates were selected for particular scrutiny:

Make	Model	Year
Audi	5000	1985
Audi	5000	1983
Buick	LeSabre	1986
Cadillac	Coupe deVille	1985
Chevrolet	Camaro	1984
Chrysler	New Yorker	1984
Mercedes	300E	1986
Mercury	Grand Marquis	1984
Nissan	300ZX	1985
Toyota	Cressida	1984

Although specific make/model/year vehicles are cited above, these vehicles are representative of a much larger group. Not all of the above listed vehicles have unusually high RSAI rates; some were chosen so that the study included certain design approaches which are used throughout a large number of models produced by the same manufacturer. Accident investigations and other vehicle tests included a broad range of vehicles.

Procedure

To accomplish this, TSC:

- convened a panel of independent experts in various disciplines related to SAI concerns to review this material with TSC,
- collected the relevant literature and case documentation on the vehicles,
- interviewed SAI-involved drivers,
- studied the fuel-systems, braking systems, and driving controls of the vehicles,
- performed appropriate tests and experiments or arranged for their conduct at NHTSA's Vehicle Research and Test Center (VRTC), and
- documented the findings and conclusions.

TSC and the Panel were specifically charged with the responsibility to consider all of the potentially viable hypotheses as to the causal and contributing factors of SAI and to specify tests of each hypothesis through both engineering analyses and experimentation, wherever feasible.

In the study the following logical assumptions were used:

- SAI could be the result of a single primary causal factor or could result from the action of a number of factors which contribute to or increase the likelihood of an SAI.
- Factors related to SAI occurrence can include power-train design, brake system design, and vehicle ergonomics (particularly pedal configuration).
- An SAI must involve a significant increase in engine power, which could be caused by a failure in an engine-control system or a pedal misapplication (inadvertent depression of the accelerator instead of, or in addition to, the brake).

- If the SAI begins with a vehicle-system malfunction, loss of control could occur through braking system failure or the driver's failure to press the brake with sufficient force and/or the driver inadvertently pressing the accelerator.

- If the SAI is initiated by a pedal misapplication of which the driver is unaware, loss of control can occur.

- The location, orientation, and force-deflection characteristics of pedals can influence the probability that the driver will mistake one pedal for another.

- If the cause of an SAI is an electro-mechanical or mechanical failure, it should produce evidence of failure.

- If the cause of an SAI is an intermittent electronic failure, physical evidence may be very difficult to find, but the failure mode should be reproducible either through in-vehicle or laboratory bench tests.

- The vehicles studied may or may not share the same causal and contributing factors.

The study covered :

- engines and their controls, as well as transmissions, to determine whether and how they might produce unwanted power;

- the role of electromagnetic and radio-frequency interference (EMI/RFI) and other environmental variables in stimulating malfunctions in critical engine controls;

- braking systems, which were examined with a view as to how they could fail momentarily but spontaneously recover normal function; and

- the role of human factors or ergonomic control design considerations which might lead to pedal misapplications.

Findings

Powertrain

In the course of its investigations, TSC encountered a substantial number of incidents in which malfunctions of the vehicle caused unwanted and substantial power output. The vast majority of these were mechanical in nature. These were mainly broken or ill-fitting parts in the throttle assembly or accelerator linkage which caused the throttle to remain open even when the driver's foot was off the accelerator. In most cases of mechanical failure, they were easy for an investigator to recognize.

Electronic faults leading to increased engine power were found to occur in the idle stabilizer systems of some Audi 5000s. When certain failure modes occurred in these models, the power-output increase produced an acceleration of less than 0.3 g for less than 2 seconds. While this acceleration is significant, it is far less than the full-power conditions characteristic of SAI. Two experimental studies of driver behavior were cited which demonstrated that such deliberately induced accelerations could startle some drivers into making pedal misapplications. In the other make-models evaluated, the maximum acceleration resulting from an idle stabilizer fault is less than 0.3 g (producing only excessive creep), and thus is less likely to startle the driver. It was concluded that such a fault could not provide the high power characteristic of an SAI, but could have startled the driver and thereby contributed to a pedal misapplication leading to high-power acceleration.

A few verified instances of cruise-control failure leading to wide open throttle were reported, but they occurred when the vehicle was already travelling at considerable speed and their causes were readily detected in post-incident investigations. In all of these instances, application of the brake caused the cruise control to disengage and usually allowed the vehicle to stop without crashing.

Extensive laboratory testing of the operation of cruise controls under stress from temperature extremes, power supply variations, EMI/RFI and high-voltage discharges has demonstrated no failure modes of any relevance to SAI. Analysis of their circuitry shows that for nearly all controls designed in the past few years, two or more independent, intermittent failures would have to occur simultaneously to cause throttle opening in a way that would be difficult to detect after the incident. The occurrence of such simultaneous, undetectable failures is virtually impossible. Among the cruise control systems examined in this study, only one has been shown to be capable of causing throttle opening as a result of a single-point failure, namely that used on the 1983 Audi. These could conceivably have played a role in a small number of incidents, but most vehicles which experienced SAI were not equipped with such units and no such failure has ever been documented.

Failures in other electronic controls, notably fuel-system control computers, were judged to be incapable of causing the engine power required to cause an SAI because they do not actuate the throttle on any car. Substantial throttle opening is required to provide the airflow into the engine necessary for high power output.

Vacuum-hose and other leaks which increase the flow of air into the intake manifold can produce only small increases in power because the resulting incremental fuel flow is quite limited. Furthermore, such leaks should be easily detectable in a post-SAI investigation, but such evidence has not been reported.

Braking system

In the typical SAI, the driver stated that the vehicle did not stop even though the brakes were fully applied, and reported brake failure. Yet the physical evidence which must accompany brake failure was evident in only a handful of the thousands of SAI involved vehicles reported to NHTSA. No plausible mechanisms could be identified for temporary, self-correcting brake failure which are relevant to SAI. Hence, actual brake system failure plays no significant role in SAI.

Less-than-expected brake effectiveness could be interpreted by the driver as brake failure. Every vehicle tested showed some increase in minimum stopping distance when its throttle was held wide open during braking. Factors such as engine power, drive-wheel configuration (front/rear wheel), front/rear weight bias, and direction of travel affect both the minimum stopping distance and the required brake-pedal effort. For three of the tested vehicles, in the extreme wide-open-throttle test condition, the force necessary to stop the vehicles in the minimum distance was beyond the capability of weaker drivers. This condition would be relevant in situations in which the throttle became stuck open after the driver pressed the accelerator pedal. It could also be relevant in cruise-control failures resulting in throttle opening at speed; (however, such failures, in which the cruise control could be neither overriden nor disengaged by pressing the brake pedal, are seen as almost impossible). This condition could also be relevant in situations in which the driver has pressed both the brake and accelerator pedals simultaneously. Weaker drivers may not press hard enough on the brake pedal to overcome the effect of also pushing on the accelerator pedal. However, for most SAI, the most plausible cause of an open-throttle condition while attempting to brake is pedal misapplication, which is likely to be perceived as brake failure.

Human factors

Human factors play a large role in the SAI problem. Pedal misapplications are the most probable explanation for the vast majority of sudden acceleration incidents in which no vehicle malfunction is evident. Even in cases where vehicle malfunctions exist which startle or otherwise distract the driver, it is often pedal misapplication which is the direct cause of high engine power. It is hypothesized that the high SAI-complaint rates for certain make-model vehicles are likely to be related to the following vehicle control characteristics:

- relatively close lateral pedal placements (increasing the likelihood of pedal misapplication);
- pedal force displacement attributes that result in similarity of feel (thus reducing the chances that an error will be recognized);
- pedal travel, vertical offset, and other characteristics which permit engine torque to exceed brake torque when the driver's foot overlaps both pedals; and
- sufficient vehicle acceleration capability to make the consequences of the error occur before the driver has time to take corrective action.

Although all of the vehicles with the highest RSAI rates possess the characteristics, there are some vehicles with these characteristics which do not have particularly high SAI complaint rates. Other variables, such as the angular placement of pedals, engine noise levels, etc. may also influence the probabilities of occurrence and of prompt recognition of a pedal misapplication.

Recommendations

Three potential approaches to reduce pedal misapplications related to SAI through design changes were identified:

- moving the pedals further apart laterally, thus reducing the possibility of stepping on both pedals with the same foot or stepping on the wrong pedal;
- raising the brake pedal with respect to the accelerator, making the pedals more distinguishable and reducing the consequences of stepping on both pedals; and
- installing automatic shift-locks (which require that the driver apply the brakes before putting the car in motion), thus eliminating the possibility of engaging the transmission while

the accelerator is depressed, and also effectively training drivers to use correct foot placement consistently so that under conditions where the driver is startled or disoriented misapplications will be less likely.

These design approaches could not completely eliminate SAI, but each could contribute, alone or in combination, to a reduction in the frequency of its occurrence. While the majority of automobiles in use in the United States already have pedal configurations consistent with the first two approaches, it must be recognized that such configurations may have other effects on driver braking performance. For example, they may slightly increase the time required to begin braking. Such effects must be quantified and evaluated before making any recommendations for pedal-design changes. A major study of this topic is currently in progress under the sponsorship of NHTSA's Office of Research and Development.

The automatic shift-lock has been adopted or is being considered by a number of manufacturers. Reported complaint rates for cars retrofitted with shift-locks have been lower than for comparable cars without them. This approach has no adverse consequences for safety and should also provide some ancillary benefits, such as preventing unattended small children from shifting a car out of "Park."

An Examination of Sudden Acceleration

1.0 INTRODUCTION

1.1 BACKGROUND

In recent years as the term "sudden acceleration" has been popularized by the media, there has been a trend toward using it in complaints about any incident involving an unexpected change in vehicle speed, including throttle sticking, excess idle speed, engine surging, unintended acceleration occurring when the vehicle was already travelling at considerable speed, etc. This overuse of the term has inflated SAI statistics. To differentiate them from other types of problems with unwanted engine power, "sudden acceleration incidents" (SAI) are defined for the purposes of this report as unintended, unexpected, high-power accelerations from a stationary position or a very low initial speed accompanied by an apparent loss of braking effectiveness. In the typical scenario, the incident begins at the moment of shifting to "Drive" or "Reverse" from "Park." Most of the reported incidents terminate in some form of collision with another vehicle or fixed object and include driver statements concerning lack of braking effectiveness. Incidents which are made known to NHTSA are "Reported Sudden Acceleration Incidents," hereinafter abbreviated as RSAI.

1.2 OBJECTIVES

Over the past 15 years, the NHTSA has conducted more than 100 separate investigations of SAI complaints involving more than 20 manufacturers. Forty-four of them have been opened since 1980, resulting in eleven recalls. Initially they were treated as unrelated matters with each considered on its own merits and without any attempt at an overview across the many different makes and models affected.

In order to secure an independent review of the current state of understanding of the sudden acceleration phenomenon and to explore topics not fully investigated previously, NHTSA requested that the Transportation Systems Center collect the relevant literature and case documentation, examine the braking and fuel-system controls of ten vehicles with above-average RSAI rates, conduct experiments as required, and engage a Panel of outside experts in various disciplines to review this material and report its findings and conclusions.

This document reports the conclusions of this study based upon information obtained from incident-involved drivers, review of the literature, examination of the components and technical documents provided by the manufacturers, extensive measurement of the behavior of the vehicles under simulated fault conditions at the Vehicle Research and Testing Center, laboratory simulations of the effects of interference sources on cruise controls, expert knowledge and panel discussions held at TSC.

1.3 PANEL MEMBERSHIP

The panel membership was as follows:

Name	Affiliation	Area of Expertise
John Adams	National Institute of Standards and Technology	Electromagnetic and Radio-Frequency Interference
David Fischer	Arthur D. Little, Inc.	Analog Circuitry
John Heywood	Massachusetts Institute of Technology	Engine Controls
Louis Klusmeyer	Southwest Research Institute	Brake Systems
Raymond Magliozzi	Good News Garage	Mechanical Diagnosis
Philip Sampson	Tufts University	Human Factors
Gary Stecklein	Southwest Research Institute	Transmissions
Benjamin Treichel	Southwest Research Institute	Digital Circuitry

Each panel member's curriculum vitae is contained in Appendix A.

2.0 DATA SOURCES

In the course of the many investigations of sudden acceleration by NHTSA in recent years, the collection of incident reports and technical documentation has become quite voluminous. In order to focus this study, detailed technical analysis was concentrated on the following vehicles for which significant numbers of sudden-acceleration complaints have been received:

Table 2-1: Listing of vehicles subjected to detailed analysis.

Make	Model	Year
Audi	5000	1985
Audi	5000	1983
Buick	LeSabre	1986
Cadillac	Coupe deVille	1985
Chevrolet	Camaro	1984
Chrysler	New Yorker	1984
Mercedes	300E	1986
Mercury	Grand Marquis	1984
Nissan	300ZX	1985
Toyota	Cressida	1984

For each of these vehicles the following types of data were acquired:

1. Complete shop manuals with supplementary electrical wiring diagrams where available, purchased through commercial sources (Appendix D).

2. Relevant studies performed by NHTSA, its contractors and TSC (Appendix D).

3. Copies of test reports, studies, or analyses of the sudden acceleration problem performed by each manufacturer or its suppliers, contractors, etc., acquired by the Office of Defects Investigation from all of the firms

listed above as well as BMW, Honda, Mazda, SAAB, Subaru, and Volvo. The letter requesting this information is reproduced in Appendix B.

4. Extensive technical documentation, including proprietary material, was received for the electrical, braking and engine-control systems. These responses included complete schematic and parts-layout diagrams for the engine-control computers and cruise-control system as well as the source-code listing for control programs. Appendix C contains a copy of the letters detailing these requirements.

5. Samples of the engine-control computer and (if separate) cruise-control computer and idle-stabilizer controller were also received.

In addition to the vehicle-specific material listed above, scores of articles from magazines and newspapers dealing with SAI were acquired and reviewed. Such articles tend to repeat one another, but several of the more comprehensive ones are included in the Technical References (Appendix D).

The Society of Automotive Engineers sponsors numerous technical meetings dealing with technological developments and problems in various types of automotive components. A number of volumes of conference proceedings have dealt with topics germane to SAI. These were acquired and are also listed in Appendix D.

The Office of Defects Investigation (ODI) provided its entire database of consumer complaints of sudden accelerations as well as a sample of a hundred written complaints including correspondence and other attachments. Arrangements were made with the ODI Hotline to refer complainants with SAI problems in the Boston area to TSC for more extensive questioning and follow-up visits where interesting problems arose. Telephone interviews of approximately 20 owners and occasional field inspections of vehicles were conducted with these as well as a few other owners identified by other means.

NHTSA's Vehicle Research and Test Center (VRTC) conducted extensive testing of acceleration and braking performance under various simulated fault conditions for a vehicle representative of each of the vehicles listed in Table 2-1 or a close substitute. These data are described fully in Appendix E. Determination of the susceptibility of certain cruise controls to malfunction as a result of EMI/RFI or environmental extremes was done at TSC, as described in Appendix F. Measurements of pedal characteristics were also done by TSC staff and are reported in Appendix G.

Because of the unusually high rate of reported SAI in the Audi 5000, that vehicle has been subjected to much more intense scrutiny than any other. As part of TSC's work for NHTSA, a detailed analysis of the Audi 5000 was begun early in 1987. The product of that study is reproduced in its entirety as Appendix H. Where appropriate, the reader is also referred to sections of the Audi 5000 analysis in Appendix H for detailed engineering discussions.

3.0 TECHNICAL DISCUSSION AND CONCLUSIONS

The following logical assumptions were used as the basis for the design of experiments and analyses:

- SAI could be the result of a single primary causal factor or could result from the action of a number of factors which contribute to or increase the likelihood of an SAI.
- Factors related to SAI occurrence can include power-train design, brake system design, and vehicle ergonomics (particularly pedal configuration).
- An SAI must involve a significant increase in engine power, which could be caused by a failure in an engine-control system or a pedal misapplication (inadvertent depression of the accelerator instead of, or in addition to, the brake).
- If the SAI begins with a vehicle-system malfunction, loss of control could occur through braking system failure or the driver's failure to apply the brake with sufficient force and/or the driver inadvertently pressing the accelerator.
- If the SAI is initiated by a pedal misapplication of which the driver is unaware, loss of control can occur.
- The location, orientation, and force-deflection characteristics of pedals can influence the probability that the driver will mistake one pedal for another.
- If the cause of an SAI is an electro-mechanical or mechanical failure, this should be evident after the fact.
- If the cause of an SAI is an intermittent electronic failure, physical evidence may be very difficult to find, but the failure mode should be reproducible either through in-vehicle or laboratory bench tests.
- The vehicles studied may or may not share the same causal and contributing factors.

The study covered :

- engines and their controls, as well as transmissions, to determine whether and how they might produce unwanted power;

- the role of electromagnetic and radio-frequency interference (EMI/RFI) and other environmental variables in stimulating malfunctions in critical engine controls;

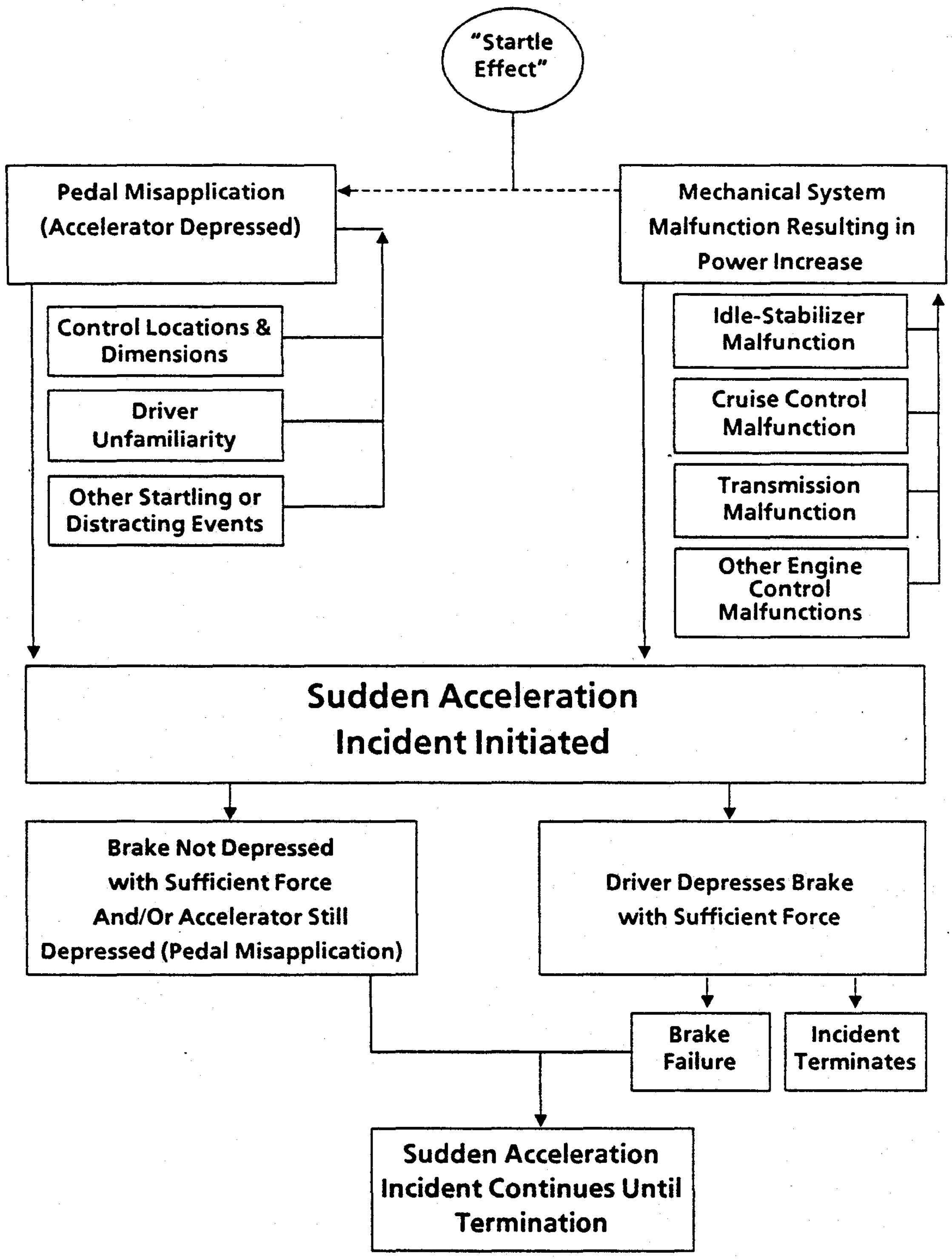
- braking systems, which were examined with a view as to how they could fail momentarily but spontaneously recover normal function; and

- the role of human factors or ergonomic control-design considerations which might lead to pedal misapplications.

Figure 3.0-1 presents a fault-tree analysis showing all of the possible events involved in an SAI. A large increase in engine power must occur by definition. This can be caused by a vehicle malfunction (a failure of one or more of the engine systems shown in Figure 3.0-1) or a pedal misapplication on the part of the driver.

If a vehicle malfunction is the initiating factor, loss of control can occur if the brakes fail or if the driver inadvertently presses the accelerator rather than, or in addition to, the brake or fails to apply sufficient force to the brake pedal. Should the initial event have been a pedal misapplication, loss of control may ensue if the driver fails to recognize it and continues to press the accelerator.

Figure 3.0-1: Sudden Acceleration Incident Scenario



3.1 VEHICLE SYSTEMS RELEVANT TO SAI

3.1.1 PROBABLE CAUSES AND FAILURE MODES

SAI as defined can occur only with a wide-open or nearly wide-open throttle. As demonstrated in Chapters 3, 4, and 5 of Appendix H, most vehicle component failures produce power decreases or at most minor increases. Only two failure modes could result in the wide-open-throttle (WOT) condition characteristic of an SAI report, cruise control malfunction or throttle sticking. The only other potential cause of the WOT condition is the misapplication of the driver's foot.

As discussed in Appendix H, other vehicle system failures could result in very brief accelerations. Such impulses may be directly responsible for some accidents in confined spaces even though the high-power acceleration characteristic of an SAI never occurs. Momentary accelerations could also conceivably startle the driver into a pedal misapplication, which could then cause high-power acceleration (as discussed in section 3.3.1).

Cruise control systems are the only vehicle component which could plausibly be suspected of *initiating* a WOT condition without the driver pressing the accelerator.

Sticking or binding in the throttle or throttle linkage could maintain WOT if the driver initially pressed the pedal to the floor, as many do prior to starting. Such sticking can have a large number of possible causes, such as frayed cables, broken return springs, rusted secondary throttles (if so equipped), misrouted hoses rubbing against the linkage, improper lubrication, etc. Such problems can result from improper original assembly, faulty repair procedures or abusive use. Ill-fitting or improperly installed parts have also been implicated in a number of cases. Interference with the accelerator pedal or linkage by floor mats, loose wiring or other miscellaneous objects is also possible. Where a mechanical or electro-mechanical failure is responsible for WOT, the diagnosis of the cause should be relatively easy because only a few parts could be responsible and these can be readily inspected by sight and by feel. For example, if the engine is still running at very high speed (3000 rpm or more) once the vehicle has stopped, or if it runs at very high speed after being restarted, it should be quite straightforward to determine which defective part in the throttle, throttle linkage or cruise control is responsible for holding the throttle open.

3.1.2 CRUISE-CONTROL MALFUNCTIONS

Because cruise controls are the only devices commonly present in automobiles, other than the drivers' feet, which can move throttle plates, they should always be investigated thoroughly following an SAI. If the cruise-control master switch is on, the gearshift is in "Drive," and the brakes are not applied, there are some control units in which only a single component failure could possibly initiate a WOT condition, particularly in the older, analog circuits, notably the 1982 Audi among the tested vehicles. (Reference 32) In virtually all recent designs for factory-installed cruise controls, where digital circuitry is now the norm, two or more component failures are required to cause an unintended throttle opening.

Most, but not all, cruise-control failures would be permanent and should be easily recognized by a mechanic after the fact. However, defective components or connections, such as leaky transistors, poor solder joints, faulty grounding, or intermittent shorts, if they existed, could cause rarely occurring faults which would be very difficult for a mechanic to diagnose. Many control systems today make use of computer programs imbedded in read-only-memory (ROM) chips. Spurious jumps in a computer program caused by some transient source of electrical or radio-frequency interference could be diagnosed reliably only at a special test facility.

While it is not extremely rare for an electronic part or solder joint to fail intermittently in a manner that is difficult to recognize or diagnose, the probability is extremely small for two or more parts or connections to fail simultaneously at exactly the right moment to cause an SAI, but then fail to do so during subsequent diagnostic tests.

All cruise controls incorporate one or more fail-safe devices designed to disable the control whenever the brake pedal is depressed. Unlike the cruise control itself, these simple switches and valves are not subject to complex, intermittent failure modes which would permit the cruise control to remain engaged during an SA incident, but which would be difficult to recognize after the fact. Intermittent failure modes for such devices result in deactivation of the cruise control. In most factory-installed cruise controls, redundant electrical and pneumatic brake-pedal defeats are employed. Chapter 4 of Appendix H describes in detail the functioning of the cruise-control in the Audi 5000, which is typical of all modern, micro-processor designs.

The credibility of cruise-control faults as an explanation for SAI is further reduced by the fact that in most designs, the actuator requires a few seconds to open the throttle fully and in some designs, can never reach or maintain the wide-open condition. For most vehicles tested, the maximum accelerations produced by simulated cruise-control failures, which were associated with faults that drove the highest possible current through the vacuum solenoids or actuators, were significantly less than those generated by drivers pressing their gas pedals to the floor. Other types of fault conditions did not cause opening at the maximum rate. Instead they resulted in peak acceleration of less than 0.1 g. Among the tested vehicles, the GM products (Buick Electra, Cadillac deVille and Camaro Z-28) exhibited the highest accelerations under simulated cruise-control faults.

VRTC conducted a series of measurements of acceleration behavior under various types of simulated cruise-control faults. Table 3.1.2-1 shows measurements of the times various vehicles require to reach 30 mph under three conditions: The first, flooring the gas pedal, generally produces the strongest acceleration. The other conditions, involving activation of the cruise control by direct short circuiting of the control's output stages or by false speed signal inputs from an external generator, caused weaker acceleration for all but one of the tested cars. The decline was substantial for the majority. Appendix E contains data describing the performance of several vehicles with high SA-complaint rates under simulated cruise-control faults.

Table 3.1.2-1: Time required to accelerate from a standing start to 30 mph for various vehicles under three conditions: (1) gas pedal floored, (2) worst-case cruise control failure, and (3) false speed signal fed to cruise control. Data shown are the shortest times measured in the Series 1 and 3 tests described in Appendix E.

Make	**Time (seconds) to Accelerate to 30 Mph**		
	Pedal Floored	**Simulated Malfunctions**	
		Worst Case	**False Signal**
Audi 5000, 1982	4.7	6.3	6.8
Audi 5000, 1984	5.3	6.5	6.2
Buick Electra, 1986	3.8	4.1	4.1
Cadillac Sedan deVille, 1985[1]	4.0	4.0	
Chevrolet Camaro Z-28, 1984	3.3	4.4	4.3
Chrysler New Yorker[2]	3.8	8.4	
Mercedes 300E, 1988	3.8	9.0	6.1
Mercury Marquis, 1984	3.7	5.6	5.9
Nissan 300ZX, 1985	3.9	4.8	5.7
Toyota Cressida, 1982	3.8	7.0	9.9

1 The integrated engine-control/cruise-control computer on the Cadillac caused the engine to shut off when a false signal was fed into it.

2 Because of its mechanical cruise control, the Chrysler unit is not susceptible to a false electrical speed signal. Worst-case failure was simulated by plugging both vents with silicone sealant and applying manifold vacuum to the servo chamber.

VRTC also measured the speeds, time, distance travelled, etc. for vehicles with simulated worst-case cruise-control faults in which the brakes were applied at one second or two seconds following the onset of forward acceleration. These tests are representative of what many accident-involved drivers claim happened, i.e., that the vehicle spontaneously accelerated from a stopped position and that they applied the brakes as hard as possible immediately, but the brakes seemed ineffective.

Because an unexpected increase in engine power may produce a slower-than-normal reaction time (normal braking reaction time is about one second), a series of tests was conducted in which braking was not initiated until two seconds after a simulated cruise-control fault. These tests revealed that application of 60 or more pounds of pedal force would have stopped all but one of the tested cars in about 30 feet or less. The exception is the 5.0 liter Camaro Z-28, which has the highest power-to-weight ratio among those tested and requires as much as 37 feet. These stopping distance data refer to the Series 6 tests described in Appendix E. Table 3.1.2-2 lists total distances travelled for each tested vehicle, as described in Appendix E.

For the numerous RSAI where cruise-control failure has been alleged, but the braking system was found to be in good working order, and the vehicle travelled a substantially greater distance than those shown in Table 3.1.2-2, it must be concluded that either the brake pedal was not appropriately applied or that cruise control failure was not a factor in the SAI.

Table 3.1.2-2: Total distance travelled (feet) by various vehicles after simulated worst-case cruise-control-induced acceleration lasting two seconds, followed by brake-pedal application. Data shown are the highest values measured in the Series 6 tests described in Appendix E. Experimental variation accounts for longer stops at higher pedal pressures in some of the runs.

Make	Total Distance Travelled (feet) For Given Brake-Pedal Force		
	60#	100#	150#
Audi 5000, 1982	17.1	14.2	16.4
Audi 5000, 1984	18.6	13.9	12.5
Buick Electra, 1986	27.3	31.7	26.9
Cadillac deVille, 1985	42.1	38.2	37.1
Chevrolet Camaro	78.8	74.4	50.1
Chrysler New Yorker[1]			
Mercedes 300E, 1988	22.3	25.8	23.7
Mercury Marquis,	31.5	32.5	29.7
Nissan 300ZX	45.7	[2]	[2]
Toyota Cressida, 1982	29.4	25.5	26.4

1 Because of its mechanical cruise control, the Chrysler unit could not be connected to the electrically operated test recorder. However, worst-case faults for this unit were simulated by plugging the vacuum release ports and applying available manifold vacuum. The peak speeds achieved in two seconds were less than 5 mph, and the stopping distances after brake application were less than 5 feet. Thus the total distances travelled were substantially less than those of any of the other cars tested.

2 Brake pedal forces greater than 60 pounds caused wheel lockup.

Complaint and vehicle-test data indicated that the probability of SAI resulting from cruise-control malfunction is extremely remote. However, there have been many allegations that malfunctions in this system resulted in SAI. To resolve these conflicting views, TSC conducted extended tests of Hella analog and digital controllers (used in the Audi 5000). In these tests, various control units were operated in the environmental chamber for several months connected to their respective vacuum servos and other associated valves and sensors. Temperature and power supply voltage and impedance were varied, while other factors such as EMI from an air-conditioner-clutch assembly and RFI from a CB transmitter were also applied. The status of each variable and the cruise-control's output state were recorded once per second. In the event of vacuum-servo actuation, the output signal was also recorded by a digital memory oscilloscope. Appendix F describes the equipment, setup and procedures employed.

Appendix F also contains an example of the output from the automatic data recording instrumentation. Ordinarily, data from time periods in which no abnormal events occurred was automatically purged. To provide the example shown and to illustrate the methodology, the vacuum servo was compressed by hand. The results from all of this testing are summarized as follows:

1. Varying power supply voltage from 10 volts to 16 volts (well outside the normal limits) and temperature from 0 F. to +150 F. produced no significant disturbances to cruise control operation. The set speed deviated slightly (less than 2 mph) from the value originally set at room temperature and normal (14 volts) power. A simulated faulty power supply connection (2 ohm resistor) had no effect.

2. Simulated and spurious EMI caused occasional momentary actuation of the vacuum pump when an external signal was being applied to the speed sensor input. Most of these incidents lasted for less than 0.1 seconds and none exceeded half a second. Because of their brevity, no significant throttle opening could occur and they would have been imperceptible to a driver had they occurred in a vehicle in use. Figure 3.1.2-1 shows an oscillogram of a typical incident while Figure 3.1.2-2 shows an oscillogram of what the output would look like if the cruise control were accelerating the car continuously for 10 seconds.

3. RFI from either a CB transmitting antenna placed inside the environmental chamber or an electro-static discharge simulator disturbed the functioning of all of the cruise controls tested. However the disturbances consisted almost entirely of momentary (less than one-half second) *throttle closings* followed by recovery to the set speed.

Every cruise control examined was designed so that it could not engage at speeds below some specific value, typically 25 to 35 mph. No instances of throttle actuation at speeds below these minima were observed. One unit did exhibit a tendency to "forget" the set speed when exposed to strong RFI so that it could not "resume." Later in the test cycle it stopped working completely. This indicates that the amount of RF energy being coupled into the cruise control was strong enough to cause damage. Except for the one permanently non-functional control, all of the effects disappeared when the CB transmitting antenna was moved back more than one meter from the cruise control under test.

At no time during any of this bench testing did any anomalies occur which could have caused any significant opening of the throttle.

In addition to this bench testing, TSC investigated three vehicles whose owners alleged that they had suddenly accelerated without the drivers' feet touching the gas pedals. The cruise-control systems of these vehicles were checked thoroughly including:

1. measurements of voltage and resistance at all significant points in the system;

2. observation of oscilloscope waveforms on critical inputs to the cruise control during several miles of driving; and

3. exposure to an intense source of RFI.

Except for one unit which would not function at all due to a misadjusted brake-pedal switch, no anomalies were found in any of these units.

The Panel considered the conditions under which a cruise control could malfunction. For most of the tested vehicles, the cruise control cannot function unless it receives electrical power through the cruise control master switch and through the gear selector inter-lock (which is designed to provide electrical power only in the upper and intermediate "Drive" ranges). If these conditions are not present and the interlock switches are in good working order, cruise-control failure is not a plausible explanation for an SAI. The exception among the tested vehicles is the Mercedes 300E, where the cruise control is always powered but which has certain redundant safety features lacking in the other designs. For the substantial proportion of SA incidents which occur in reverse, cruise-control malfunctions are not a plausible explanation for those vehicles with a gear-selector interlock, such as the Audi, unless the gearshift interlock or its wiring harness is shown to be faulty (see Appendix H, Chapter 4).

If the accelerator pedal moves down, seemingly of its own accord, in an SAI, a cruise control problem is a likely explanation. However, for the WOT condition to continue beyond the moment the driver's foot presses the brake pedal, at least one (and usually two or three) additional independent and easily recognized faults must also occur simultaneously. No evidence of such failures has been found.

For all of the reasons described above and because the RSAI rates are not significantly different for cruise-control-equipped vehicles versus those without them, cruise controls are not an important factor in SAI problems.

Figure 3.1.2-1: Oscillogram of typical RFI-induced cruise-control transient. The vacuum pump (upper trace) is energized only when this waveform is low. The vent (lower trace) is sealed only when its waveform is low. In this incident, a speed signal is being supplied from an external generator. Without such a signal present, the duration of the spike would be only a few milliseconds rather than a few hundred milliseconds and would be difficult to see at a scale of one division per second.

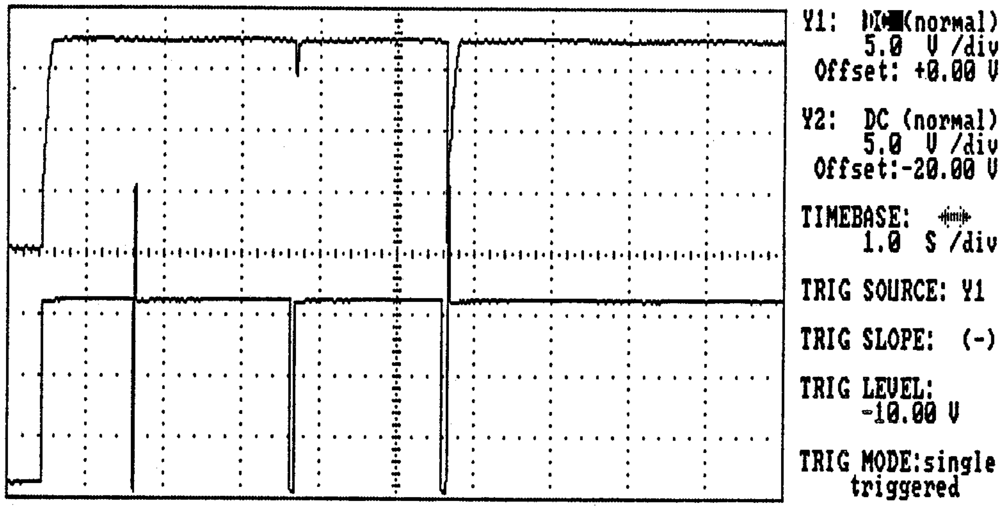
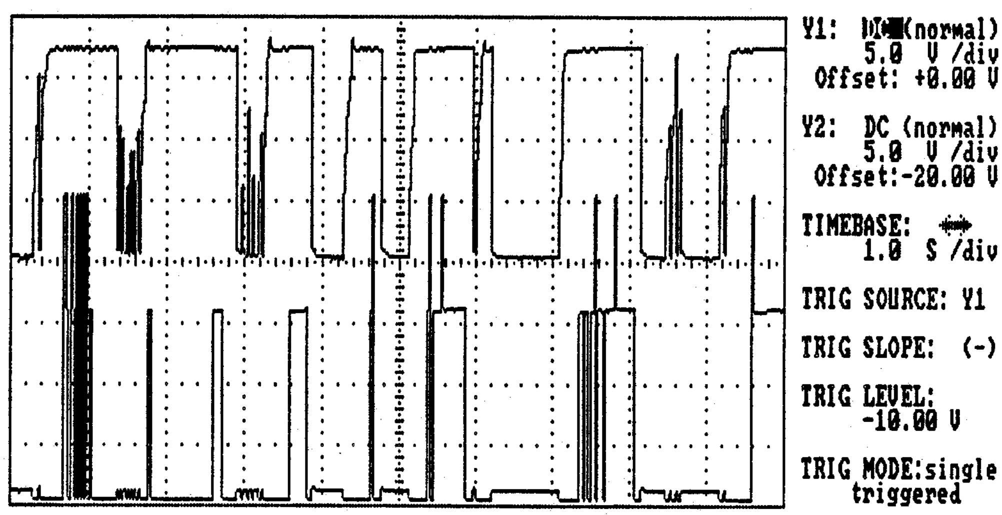


Figure 3.1.2-2: Oscillogram of cruise-control output which produces wide-open throttle in about five seconds. Current flows through the vacuum pump and the vent-sealing solenoid only when their waveforms are low. In this example the duty cycle is about 40%.



3.1.3 TRANSMISSION MALFUNCTIONS

Very few cars contain any mechanism by which the transmission can cause throttle opening. Therefore, it is impossible for transmission malfunctions to cause SAI in most cars.

The one notable exception in the group of vehicles examined was the Audi 5000 prior to model year 1984, which had a rigid linkage between the throttle and the transmission kick-down lever. By deliberately inducing several part failures and by deliberately pressurizing certain passages in this transmission, the kick-down linkage could be made to open the throttle. (See Chapter 5 of Appendix H for a detailed discussion of this topic.) However, TSC could identify no plausible scenario by which this abnormal pressure could arise, or how the required malfunctions could fail to be evident after the fact. In subsequent model years, this rigid linkage was replaced with one which did not permit throttle actuation, but there was no reduction in the RSAI rate.

Although there is no evidence to support the idea that transmission malfunctions could cause throttle opening, there have been a number of documented incidents in which a faulty safety interlock switch permitted a vehicle to start in gear. This unexpected behavior obviously startled drivers and could easily contribute to a pedal misapplication. There have also been incidents in which a driver started in "Neutral," thinking "Park" was selected, or vice versa. (In some of these incidents the indicator was broken or unreadable.) When the driver then shifted into gear, the vehicle's movement was then in the opposite direction from what was expected. Again, this startling movement could have made pedal misapplication more likely.

3.1.4 IDLE-SPEED CONTROL MALFUNCTIONS

In gasoline engines, only a substantial opening of the throttle which produces an appropriate fuel-oxygen mixture can produce rapid acceleration. Excess fuel from some malfunction in the fuel system will cause flooding and stalling, not increased power. Similarly, a significant air leakage which bypasses the fuel-metering system's air-flow sensor or carburetor throat will result in a lean mixture, reducing power.

The idle bypass system is also capable of providing moderate increases in engine power. It provides a path by which the air required to support combustion may enter the engine accompanied by the appropriate amount of fuel. The cross-section of the bypass valve is much smaller than that of the throttle so that the amount of power that can be developed by this route is relatively small, for most cars considerably less than 20 horsepower. One exception is the Audi 5000 which is capable of a more substantial idle-stabilizer power increase, a full 20 horsepower. The resulting acceleration in this vehicle has an initial value of nearly 0.3 g and decays in less than 2 seconds to only a few hundredths of a g. Chapter 3 of Appendix H describes the Audi idle stabilization system. It is typical of modern designs in its function, but was sized relatively larger than most other passenger cars. Several other vehicles employ idle-stabilization systems which can generate significant acceleration impulses if they malfunction.

If the idle stabilizer opens abruptly, the brief acceleration may startle some drivers into making a stab for the brake pedal, as discussed in Section 3.3.2. Especially when the driver has not yet settled into his or her normal orientation with respect to the pedals, this rushed attempt to brake may increase the likelihood of a pedal misapplication. In the case of the Audi 5000, a significant number of the earlier versions of the idle stabilizer reportedly experienced malfunctions causing intermittent incidents of high idle speed. These failure modes were verified during tests conducted by TSC, as described in Appendix H, Chapter 3. These parts were replaced in a recall campaign.

Other parts failures, notably detached hoses, could create unintended entrance paths for combustion air and increased power output. However in order to generate a substantial amount of power, it would be necessary that the leak also cause increased fuel flow, i.e. by sucking more air through the carburetor throat or the air-flow sensor. Since the sensor is located ahead of the throttle in every fuel-injected design, it is virtually impossible for this to occur by any means other than deliberate sabotage. In carburetors, the throat and throttle are immediately adjacent with no possibility of leakage into the connecting passage in a way that would not be readily apparent, such as a cracked carburetor body.

In some vehicles, leaks into the intake manifold could cause modest increases in power output through the action of the fuel-air mixture compensation system. That is, the leak would initially cause a lean mixture, which would be detected by the oxygen sensor in the exhaust gas, which would trigger increased fuel-flow. However, these systems are designed so that the maximum additional fuel they can provide is relatively small. In older fuel-injection systems without an air-flow sensor and in many carburetors, there are various mechanisms by which a vacuum leak could cause modest increases in fuel flow. However, in no case does the power output approach that characteristic of an SAI. As with the idle-stabilizer, the sudden occurrence of a minor power increase might be responsible for startling a driver and thereby triggering a pedal misapplication.

Leaks can generally be spotted very easily both visually and by the sucking noise they produce. Furthermore they cause rough, erratic idling which is immediately apparent to drivers. The lack of reports of such malfunctions in the RSAI data base suggests that they are not a significant causal factor.

3.1.5 BRAKE SYSTEM MALFUNCTIONS

No plausible mechanism for temporary, self-correcting brake failure has been identified which has any relevance to SAI. Every passenger car is capable of stopping eventually even with its accelerator pushed to the floor (so long as its brakes are given normal maintenance and applied with sufficient force). Chapter 6 of Appendix H describes the operation of the Audi braking system in great detail and concludes unequivocally that no SAI-related brake failure modes exist which leave no readily detectable evidence of their occurrence.

All of the tested vehicles were equipped with power brakes. In the braking test, vehicles which were initially stationary and with the brakes set firmly, remained stationary even with the throttle opened wide. These tests were conducted on a clean, dry, well-maintained brake-test pad. However, based on evidence provided by Mercedes-Benz, high-power, rear-wheel-drive autos on a wet or slippery surface may exhibit wheel spinning resulting in slow, jerking movement under WOT with brakes firmly set (Reference 23).

Under wide-open-throttle (WOT) conditions, braking performance can be degraded because:

1. brake torque is partially offset by engine torque; and

2. in vacuum-assisted power brakes, intake manifold vacuum is at a minimum under WOT and therefore available boost is quickly reduced, particularly if the brake pedal is pumped.

Thus under WOT the minimum stopping distance from any given initial speed can be greater than for a normal, closed-throttle stop and the required pedal effort may be substantially increased. Because the pedal force required to achieve a given deceleration is far more than the driver normally applies, many drivers may describe this degraded performance as "brakes not working."

As noted above for vehicles with vacuum-boosted brake systems, if the throttle is held wide open there will be little or no manifold vacuum and therefore little or no build-up of boost. Conversely, vehicles with hydraulic boosters, such as the Audi 5000, will develop boost pressure more rapidly than normal under WOT, because of high engine rpm.

There is another normal characteristic of power brakes which might under certain circumstances lead a driver to think the brakes were malfunctioning. If a vehicle remains parked for a considerable period, the accumulated vacuum or hydraulic pressure is gradually dissipated by leakage. Thus when the vehicle is first started, there is no boost. Therefore in the first few seconds, much greater pedal force and pedal travel are required to achieve a given amount of braking action than would normally be the case. It must be stressed that the problems associated with a drained accumulator or vacuum reservoir could apply only to the small proportion of incidents which occur in the first few seconds after engine start.

So long as the driver exerts sufficient brake-pedal force to lock the driving wheels, the stopping distance is the same regardless of how much power the engine is developing. Table 3.1.5-1 shows the results of tests conducted at VRTC to measure stopping distances under WOT. In these tests two conditions are represented; in the first, the throttle was held open for the entire test and the brakes were applied two seconds after pressing the throttle. In the second, the throttle was held open for two seconds but released at the instant the brakes were applied.

As can be seen in Table 3.1.5-1 and Figure 3.1.5-1, for cars with moderate low-speed torque and front-wheel drive, such as the Audi 5000, the minimum stopping distance is similar for both conditions. For very low initial speeds, the increase in stopping distance was small. For the rear-wheel-drive vehicles tested, the WOT-stopping distances increased significantly with 60 lbs. of pedal force, because there was more engine torque offsetting brake torque. In the case of the 5.0 liter Camaro Z-28, the WOT-stopping distance increased by a factor of three or more compared to normal stopping distance. At higher levels of pedal effort, stopping distances became shorter for all conditions, but a substantial disparity between open-throttle and closed-throttle conditions remained for the high-power, rear-wheel-drive models.

Braking in reverse is often less effective than braking when moving forward, especially for a high-powered, rear-wheel-drive model. For such vehicles travelling in reverse at 30 mph under the WOT test conditions, measured minimum stopping distances ranged from three to six times the normal closed throttle stopping distance even though the braking systems were in perfect working order. It should be noted that in the vehicles tested, as in nearly all current designs, braking systems are designed to work more effectively when the vehicle is travelling forward.

Table 3.1.5-1: Results of tests with WOT from a standing start and with brakes applied after two seconds at 60 pounds. At higher brake pedal forces, shorter stopping distances were recorded. These data are extracted from Appendix E, Series 4 and 5 and represent the highest values measured during multiple tests. Experimental variation results in some small anomalies in these data. For example, the peak speeds differ slightly for the same car, even though they should be identical. Averaging multiple runs would have reduced these anomalies, but the intent here is to show worst-case performance.

	Throttle Open While Braking			Throttle Closed While Braking		
Vehicle	Peak Speed (MPH)	Stopping Distance (Ft)	Total Distance (Ft)	Peak Speed (MPH)	Stopping Distance (Ft)	Total Distance (Ft)
Rear Drive						
Chevrolet Camaro (Z28)	19.8	82.1	120.5	18.0	22.3	56.6
Mercury Marquis	17.2	45.7	74.2	18.5	19.5	55.5
Mercedes 300E	13.7	51.0	69.8	15.5	14.6	43.2
Nissan 300ZX	17.2	38.7	68.7	15.4	13.6	42.3
Toyota Cressida	14.2	32.6	54.9	17.2	17.2	47.2
Front Drive						
Audi 5000 '82	13.4	17.0	39.3	14.2	20.2	41.9
Audi 5000 '84	14.5	15.1	37.7	14.5	13.7	37.0
Buick Electra	16.2	23.8	49.5	16.0	16.2	43.2
Cadillac deVille	16.4	32.4	62.7	19.0	20.8	58.0
Chrysler New Yorker	13.8	44.9	67.5	14.7	14.7	39.2

Figure 3.1.5-1: Graphic comparison of stopping distances for WOT versus closed throttle for various cars from speed reached after two seconds when 60 pounds of brake-pedal force were applied. Source: Appendix E, Series 4 and 5 tests. The disparity in stopping distances for the Chrysler New Yorker compared with other front-wheel-drive cars did not occur at the higher brake-pedal forces of 100 and 150 pounds.

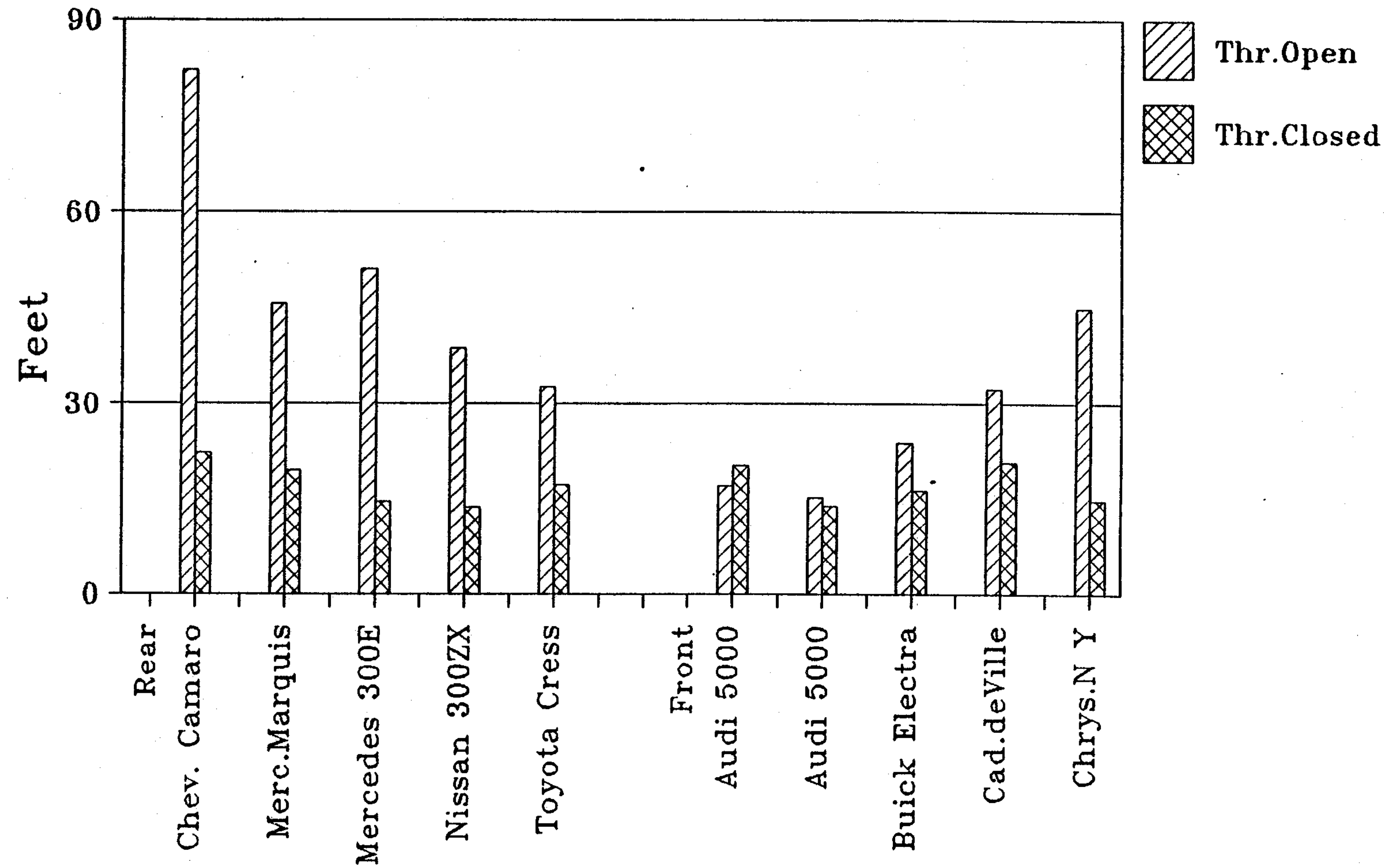


Table 3.1.5-3 shows the results of braking tests from an initial speed of 30 mph in reverse. Brakes were applied with a force sufficient to produce minimum stopping distance (this force was determined experimentally). Under one test condition the throttle was held open until the vehicle came to a stop. In these extreme conditions, curving skid marks and other evidence of directional instability were abundant, except for the one vehicle equipped with an anti-lock brake system. In the other test series, the throttle was released at the onset of braking, which caused no problems with directional control.

Table 3.1.5-3: Comparison of minimum stopping distances in reverse from 30 mph with throttle wide open or closed for selected high-power, rear-wheel-drive cars. These data are extracted from Appendix E, Series 9 and 10 tests.

Make/Model	WOT Stopping Distance (feet)	Closed Throttle Stopping Distance (feet)	Ratio (WOT/ Closed)
Chevrolet Camaro	291.6	53.5	5.5
Mercedes 300E, 1988	204.8	64.3	3.2.
Mercury Marquis, 1984	117.7	49.9	2.7

In the same series of WOT tests, measurements were made of the brake-pedal forces required to achieve minimum stopping distance in reverse for the three vehicles. The worst-case maximum pedal force measured was 190-200 pounds for the Mercedes 300E, 180 pounds for the Camaro Z-28, and 175 pounds for the Mercury Marquis. These forces are several times higher than those required with the throttle closed and beyond the strength of approximately 50% of all females and 2.5% of men (Reference 11). For the tests conducted in "Drive," the pedal forces required to stop quickly were somewhat lower. In either direction, drivers of these high-powered rear-wheel-drive cars would experience much longer stopping distances with the throttle held open than with a normal closed throttle.

3.2 ELECTROMAGNETIC AND RADIO-FREQUENCY INTERFERENCE

Due to the presence of electronic engine controls, electromagnetic and radio-frequency interference (EMI/RFI) have been hypothesized to be a factor in SAI.

3.2.1 ELECTROMAGNETIC INTERFERENCE

Electromagnetic interference refers to electrical noise arising from changing current flows. Abrupt interruptions of large currents generate the more severe problems. Among the most familiar examples is impulse noise heard on the car radio from lightning or nearby faulty spark-plug wiring. AM radios are inherently sensitive to even very weak EMI conditions, but the rest of the vehicle's electronics will not be disturbed until the strength of the EMI is several orders of magnitude greater.

By far the strongest potential source of EMI in a vehicle electrical system is an intermittent connection to the battery or alternator. Under worst-case conditions, interrupting these circuits can produce transients with energies approaching 100 joules (Reference 13) and voltage spikes ranging from +80 to -210 volts (Reference 27, McCarter). Such energetic pulses can easily destroy most solid-state devices. However, all automotive electronics contain filters designed to protect against EMI. The design of such filters is well understood and adequate in most cases.

Instances of cruise-control malfunction causing the throttle to be held open and triggered by EMI have been documented (Reference 13). In this case a batch of transistors which did not quite meet their specifications was used in the output stages of the cruise-controls. When these units were subjected to the stress of alternator-circuit interruptions, their output stages broke down and permitted current to flow to the solenoid which caused the throttle to open. No accidents are known to have resulted since the brake-pedal vacuum dump defeated the cruise control, and the brakes were unaffected. This problem was discovered by the manufacturer, and the vehicles containing the defective transistors were recalled.

Although EMI could have no effect on braking except for the very small number of vehicles with electronic anti-lock systems, it is possible that EMI has induced driver-startling malfunctions in cruise controls, idle stabilizers and other engine controls. Such malfunctions are possible where substandard parts and/or marginal protective circuitry have been used.

If SAI malfunctions were EMI related, the incident reports would be expected to contain some mention of symptoms of electrical system problems, such as dimming lights, starter-motor problems or non-functioning accessories. One would also expect such SAI reports to be concentrated in higher-mileage cars, because as vehicles age, corrosion, wear on brushes and contacts, etc. lead to an increased frequency of the sort of electrical problems that generate severe EMI. Since these characteristics are not evident in the complaints, TSC concluded that EMI is not an important cause of such malfunctions.

3.2.2 RADIO-FREQUENCY INTERFERENCE

Radio-frequency interference (RFI) results from the presence of transmitted signals and is often known to cause disruption of electronic systems. Therefore the Panel considered the hypothesis that RFI could be responsible for SAI in passenger cars. It is plausible that RFI might cause malfunctions in engine controls. As noted in Section 3.1.2, experiments conducted at TSC have shown that cruise controls can easily be disturbed momentarily by a citizens' band (CB) transmitter located within one meter.

RFI-induced cruise control faults are not extremely rare and are mentioned in the literature as fairly common sources of failures leading to throttle-closure (Reference 19, A.H. Lay). However, control engineers have deliberately sought to design their products so that unintended conditions such as RFI will cause throttle closing rather than the reverse. It is plausible that in some designs, this strategy may not have been fully realized, but no examples have been brought forward thus far.

As a rule-of-thumb, field strengths of at least several volts per meter (V/m) are required to induce malfunctions. Most engine controls are designed to withstand more than 10 V/m and some are rated for more than 100 V/m. The following equation relates field strength to radiated power for distances greater than one sixth wavelength:

$$E = 5.5\sqrt{ERP}/d$$

where E = field strength in Volts per meter
ERP = effective radiated power
d = distance in meters

Source: Reference 19, A.H. Lay.

Typical wavelengths and powers for various types of radio frequency sources are as follows:

Transmitter	Wavelength (meters)	Power (Watts)
UHF TV	.3 -1	1×10^6
VHF TV	2 - 6	120×10^5
AM Broadcast	200-600	50×100^3
Amateur Mobile	2 - 6	400
Land Mobile	.6 -2	110
Citizens Band	11	5

Source: Reference 19, A.H. Lay, with land mobile power adjusted to 110 watts to reflect recent changes in technology and regulations.

Very close to a transmitter, field strengths are greater than implied by the equation above by a factor of $(\lambda/6.28)^2$, where λ is the wavelength. This near-field correction factor applies for most sources only when the transmitter is located in the vehicle in question or in another vehicle within one or two meters. For standard broadcast transmitters, the near-field may extend about a hundred meters.

Using the far-field equation and the data above, one may calculate the range at which field strengths exceed any arbitrary value for several common types of transmitters. The following table was computed for 10 V/m:

Typical Transmitter	Nominal 10 V/m Radius (meters)
UHF TV	550
VHF TV	190
AM Broadcast	123
Amateur Mobile	11
Land Mobile	6
Citizens Band	1

The wiring harness of an automobile may function as an antenna with gain, i.e., capable of receiving a stronger signal than the standard dipole used in field strength measurements. Hence the radii shown above could conceivably be increased by a factor of 10 or so to approximate worst-case conditions. Thus, it is obvious that the source of RFI must be within sight of any vehicle which is likely to be affected by it.

On-board transmitters are by far the strongest potential source of RFI commonly encountered. Fields of more than 350 V/m have been measured in a passenger car with a 100 W amateur transmitter operating, as indicated in Table 3.2.2-1. Table 3.2.2-1 shows the actual field strengths measured by the National Bureau of Standards on a number of vehicles in the proximity of various transmitters. The first portion of this table lists the field strengths measured on various vehicles with on-board transmitters and antenna locations as described in the "Comments" column. The last section gives the field strengths of several AM, FM and television broadcast transmitters at various distances from 30 feet to 300 yards. Dozens of measurements were made on each vehicle. The distribution of these measurements for various vehicles is described in the "Percentile Values" columns of Table 3.2.2-1. The principal significance of these data is that on-board transmitters are by far the most potent source of RFI and that other transmitters must be quite close by to be able to generate high field strengths.

Table 3.2.2-1: Field strengths of various transmitters as measured in various vehicles. Source: Reference 36.

E, Electric Field Strength Units: V/m

H, Magnetic Field Strength Units: A/m(V/m)

Vehicle type	Surface type	Frequency	Field type	No. of measurements	Percentile values					Comments
		MHz	E or H	N	100	95	90	75	50	
Full-size car	Metal ground	3.910	E	27	342	267	242	228	180	Ant left rear fender 100 w
Full-size car	Metal ground	7.280	E	32	164	159	148	130	108	Ant left rear fender 100 w
Full-size car	Metal ground	14.310	E	42	146	126	116	95	67	Ant left rear fender 100 w
Full-size car	Metal ground	21.400	E	40	383	319	260	213	106	Ant left rear fender 100 w
Full-size car	Metal ground	27.610	E	46	251	202	202	184	106	Ant left rear fender 100 w
Full-size car	Dry ground	40.27	E	56	190	171	150	104	58	Ant center of roof 110 w
Full-size car	Dry ground	40.27	E	47	196	178	116	75	48	Ant right rear fender110 w
Full-size car	Dry ground	162.475	E	61	201	116	82	54	30	Ant center of trunk 110 w
Full-size car	Dry ground	416.975	E	51	60	58	56	37	13	Ant center of roof 110 w
Full-size car	Metal ground	40.27	E	21	368	300	300	242	150	Ant center of roof 110 w
Full-size car	Metal ground	40.27	E	36	371	260	238	171	95	Ant right rear fender110 w
Full-size car	Metal ground	162.475	E	31	116	116	82	67	48	Ant center of roof 110 w
Full-size car	Metal ground	416.975	E	34	82	75	58	58	48	Ant center of roof 110 w
Car beside tx-car	Dry ground	40.27	E	20	48	37	37	21	15	Ant center of roof 110 w
Car beside tx-car	Dry ground	40.27	E	35	88	60	50	48	26	Ant right rear fender110 w
Car beside tx-car	Dry ground	162.475	E	18	75	75	75	34	21	Ant center of roof 110 w
Car beside tx-car	Dry ground	162.475	E	22	38	38	34	26	19	Ant center of trunk 110 w
Car beside tx-car	Dry ground	416.975	E	13	42	42	26	26	21	Ant center of roof 110 w
Full-size car	Near metal wall	40.27	E	23	212	184	184	150	82	Ant center of roof 110 w
Full-size car	Near metal wall	162.475	E	14	190	190	95	82	58	Ant center of roof 110 w
Full-size car	Near metal wall	416.975	E	12	95	95	58	48	48	Ant center of roof 110 w
Compact	Dry ground	3.91	E	36	322	295	274	249	213	Ant left rear fender 110 w
Compact	Metal ground	3.91	E	36	322	310	277	265	228	Ant left rear fender 110 w
Compact	Dry ground	7.28	E	43	232	205	192	174	130	Ant left rear fender 110 w
Compact	Metal ground	7.28	E	46	343	201	192	169	145	Ant left rear fender 100 w
Compact	Dry ground	14.31	E	32	178	158	143	134	112	Ant left rear fender 100 w
Compact	Metal ground	14.31	E	37	178	178	171	148	106	Ant left rear fender 100 w
Compact	Dry ground	21.39	E	36	213	165	136	118	88	Ant left rear fender 100 w
Compact	Metal ground	21.39	E	35	289	277	233	202	106	Ant left rear fender 100 w
Compact	Dry ground	27.61	E	39	169	116	108	80	56	Ant center of roof 80 w
Compact	Metal ground	27.61	E	42	233	207	196	143	116	Ant center of roof 80 w
Compact	Dry ground	27.61	E	36	184	174	143	105	74	Ant left rear fender 80 w
Compact	Metal ground	27.61	E	37	392	356	336	285	196	Ant left rear fender 100 w
Compact	Dry ground	40.27	E	33	171	134	106	95	67	Ant right rear roof 100 w
Compact	Metal ground	40.27	E	39	233	196	138	106	74	Ant right rear roof 100 w
Compact	Dry ground	162.475	E	28	88	75	48	29	21	Ant left rear roof 100 w
Compact	Metal ground	162.475	E	23	80	67	58	34	28	Ant left rear roof 100 w
Compact	Dry ground	416.975	E	24	82	54	50	45	15	Ant center of roof 80 w
Compact	Metal ground	416.975	E	21	56	54	52	37	15	Ant center of roof 80 w
Tractor-trailer	Dry ground	27.6	E	35	112	106	72	60	48	Ant on the roof 100 w
Tractor-trailer	Metal ground	27.6	E	33	106	106	93	82	67	Ant on the roof 100 w
Tractor-trailer	Dry ground	40.27	E	43	223	178	158	111	82	Ant on the roof 60 w
Tractor-trailer	Metal ground	40.27	E	51	190	184	171	111	82	Ant on the roof 60 w
Tractor-trailer	Dry ground	162.475	E	34	126	116	95	67	30	Ant center of roof
Tractor-trailer	Dry ground	416.975	E	40	67	52	48	26	10	Ant center of roof
Tractor-trailer	Dry ground	3.91	E	13	161	161	81	76	51	Ant on left rear fender
next to	Dry ground	7.28	E	8	116	116	116	92	58	Ant on left rear fender
car with tx	Dry ground	14.31	E	14	134	134	82	58	48	Ant on left rear fender
	Dry ground	21.39	E	7	58	58	58	48	48	Ant on left rear fender
	Dry ground	27.61	E	9	95	95	95	58	40	Ant on left rear fender
	Dry ground	27.61	E	6	75	75	75	75	58	Ant on center of roof100 w
Tractor-trailer	Dry ground	40.27	E	21	95	95	82	58	34	Ant center of roof 110 w
next to	Dry ground	40.27	E	21	67	58	50	26	21	Ant center of roof 110 w
Car with tx	Dry ground	40.27	E	21	41	40	34	26	21	Ant right rear fender110 w
	Dry ground	162.475	E	13	58	58	42	21	15	Ant center of roof 110 w
	Dry ground	416.975	E	11	47	47	26	18	15	Ant center of roof 110 w
	Dry ground	416.975	E	13	38	38	26	18	12	Ant center of roof 110 w
Tractor-trailer	Dry ground	40.27	E	20	171	116	95	48	21	Ant center of roof 110 w
next to	Dry ground	162.475	E	20	58	37	34	26	12	Ant center of roof 110 w
Tractor-trailer with tx	Dry ground	416.975	E	21	45	37	30	21	15	Ant center of roof 110 w
Full-size car	Metal ground	7.28	H	32	.239(90)	.212(80)	.207(78)	.112(42)	.090(34)	Ant left rear fender 100 w
Full-size car	Dirt ground	7.28	H	39	.425(160)	.319(120)	.239(90)	.143(54)	.066(25)	Ant left rear fender 100 w
Full-size car	Metal ground	27.6	H	33	.425(160)	.358(135)	.311(117)	.260(98)	.179(67)	Ant left rear fender 100 w
Full-size car	Dirt ground	27.6	H	23	.260(98)	.226(85)	.179(67)	.098(37)	.056(21)	Ant left rear fender 100 w
Full-size car	Metal ground	40	H	31	.358(135)	.358(135)	.239(90)	.170(64)	.093(35)	Ant right rear fender100 w
Full-size car	Dirt ground	40	H	28	.451(170)	.332(125)	.319(120)	.082(31)	.032(12)	Ant right rear fender100 w
Full-size car	Dirt ground	162	H	56	.370(139)	.179(67)	.159(60)	.074(28)	.035(13)	Ant center of trunk 100 w
Full-size car	Metal ground	162	H	58	.372(140)	.231(87)	.186(70)	.109(41)	.048(18)	Ant center of trunk 100 w
Compact	Dry ground	7.28	H	21	.504(190)	.504(190)	.404(152)	.281(106)	.234(88)	Ant left rear fender 95 w
Compact	Metal ground	7.28	H	20	.504(190)	.441(166)	.404(152)	.327(123)	.181(68)	Ant left rear fender 95 w
Compact	Dry ground	27.61	H	32	.478(180)	.430(162)	.308(116)	.085(32)	.064(24)	Ant center of roof 100 w
Compact	Metal ground	27.61	H	30	.390(147)	.348(131)	.223(84)	.181(68)	.106(40)	Ant center of roof 100 w
Compact	Dry ground	40.27	H	28	.664(250)	.467(176)	.329(124)	.215(81)	.096(36)	Ant center of roof 82 w
Compact	Metal ground	40.27	H	26	.611(230)	.518(195)	.358(135)	.215(81)	.159(60)	Ant center of roof 82 w
Compact	Dry ground	40.27	H	40	.473(178)	.451(170)	.297(112)	.242(91)	.127(48)	Ant right rear fender100 w
Compact	Metal ground	40.27	H	38	.473(178)	.438(165)	.411(155)	.297(112)	.186(70)	Ant right rear fender100 w
Compact	Dry ground	162.475	H	32	.332(125)	.215(81)	.207(78)	.080(30)	.037(14)	Ant right rear fender100 w
Compact	Metal ground	162.475	H	35	.372(140)	.305(115)	.234(88)	.098(37)	.042(16)	Ant left rear fender 100 w
Tractor-trailer	Dry ground	27.6	H	28	.518(195)	.459(173)	.340(128)	.223(84)	.133(50)	Ant on the roof 100 w
Tractor-trailer	Metal ground	27.6	H	29	.557(210)	.393(148)	.308(116)	.223(84)	.119(45)	Ant on the roof 100 w
Tractor-trailer	Dry ground	40.27	H	29	.929(350)	.717(270)	.571(215)	.324(122)	.186(70)	Ant on the roof 100 w
Tractor-trailer	Metal ground	40.27	H	28	.956(360)	.749(282)	.690(260)	.358(135)	.215(81)	Ant on the roof 100 w

Table 3.2.2-1 (cont.)

E, Electric Field Strength Units: V/m

H, Magnetic Field Strength Units: A/m(V/m)

Vehicle type	Surface type	Frequency	Field type	No. of measurements	Percentile values					Distance from Transmit Antenna (m)	Comments
		MHz	E or H	N	100	95	90	75	50		
Full-size car	Dry ground	.85	E	24	222	212	196	171	134	130 m (300 yd)	KOA, tx, 50 kW, 5/8 ant
Full-size car	Dry ground	.85	E	22	18	15	15	13	11	164 m (160 yd.)	KOA, tx, 50 kW, 5/8 ant
Full-size car	Dry ground	1.6 107.5	E	30*	164	157	106	95	82	9 m (30 ft)	KLAK-AM 5kW, FM 56 kW tx
Full-size car	Dry ground	1.6 107.5	E	29*	58	30	26	21	13	36 m (120 ft)	KLAK-AM 5 kW, FM 56 kW tx
Full-size car	Dry ground	100.3	E	27	9	8	8	6	5	91 m (100 yd)	KLIR-FM tx, 100 kW
Full-size car	Dry ground	101.5	E	33	42	40	34	30	21	30 m (100 ft)	KHEP-FM tx, 100 kW
Full-size car	Dry ground	101.5	E	25*	26	21	21	18	15	182 m (200 yd)	KHEP-FM tx, 100 kW
		180								18 m (60 ft)	KAET-TV, tx, Channel 8, 117 KW vis 16.2 kW aur
		204								18 m (60 ft)	KTAR-TV, Channel 12, 316 kW vis, 46.8 kW aur
		60								91 m (100 yd)	KTVK-TV tx, Channel 3, 100 kW, vis 15.1 kW aur
Full-size car	Dry ground	90.7 518	E	44*	60	54	50	34	18	3 m (10 ft) 3 m (10 ft)	KRWG-FM tx, 100 kW, KRWG-TV tx, Channel 22
Full-size car	Dry ground	90.7 518	E	42*	45	42	40	26	21	18 m (60 ft) 18 m (60 ft)	KRWG-FM tx, 100 kW KRWG-TV tx, Channel 22, 1620 kW vis, 350 kW aur
Full-size car	Dry ground	54	E	22	42	37	34	26	21	30 m (100 ft)	KWGN-TV tx, Channel 2, 100 kW vis, 20 kW aur
Full-size car	Dry ground	66	E	26	11	9	9	7	7	46 m (50 yd)	KOA-TV tx, Channel 4, 100 kW vis, 35 kW aur
Full-size car	Dry ground	82	E	34	58	40	30	21	15	46 m (50 yd)	KRMA-TV tx, Channel 6, 100 kW vis, 15.1 kW aur
Full-size car	Dry ground	82	E	7	21	21	21	15	13	273 m (300 yd)	KRMA-TV tx, Channel 6, 100 kW vis, 15.1 kW aur
Tractor-trailer	Dry ground	0.85	E	22	921	921	824	759	568	3 m (10 ft)	KOA, 5/8 λ ant, 50 kW
Tractor-trailer	Dry ground	0.85	E	22	412	391	349	240	184	21 m (70 ft)	KOA, 5/8 λ ant, 50 kW
Compact	Dry ground	0.85	E	13	368	368	368	319	212	3 m (10 ft)	KOA, 5/8 λ ant, 50 kW

*Resultant field strength from more than one transmitter.

Figure 3.2.2-1 shows field strengths, expressed in Volts per meter on a typical full-size car with 100 watt amateur radio transmitter operating. Figure 3.2.2-2 shows the means of the worst-case E-field measurements for three types of vehicles. For this series of tests, the strongest fields affecting motor vehicles were associated with long-wave (most commonly, AM broadcast) and CB transmitters. The very high values shown for CB resulted from the use of illegal, 100-Watt amplifiers. Legal CB units are limited to 5 Watts.

If any cruise controls were susceptible to throttle opening because of RFI, this malfunction would be most likely to show up in cars with on-board transmitters, which number in the millions, mainly CB and cellular phones. Thus one would expect a substantial number of SA incident reports to contain statements that the acceleration began just as the transmitter was switched, on or just as the microphone was keyed, or just as a call was placed on a cellular telephone. The absence of such reports supports the view that RFI is not a significant or even a measurable cause of SAI.

When electronically controlled anti-lock braking systems first appeared on heavy trucks several years ago, there were a number of documented cases of malfunctions due to RFI. Very few passenger cars have any electronic components controlling their brakes. Among the cars examined in this study, only the Mercedes has anti-lock brakes as standard equipment. In this system, even if the anti-lock failed, the braking system would still function and stopping distances would not be appreciably different for the relatively low speed situations characteristic of SAI. Hence there is no possibility of RFI causing the alleged brake failure characteristic of SAI.

Figure 3.2.2-1: Field strength measurements on a typical full-size car. The numbers are field strengths expressed in volts per meter. Source: Reference 36.

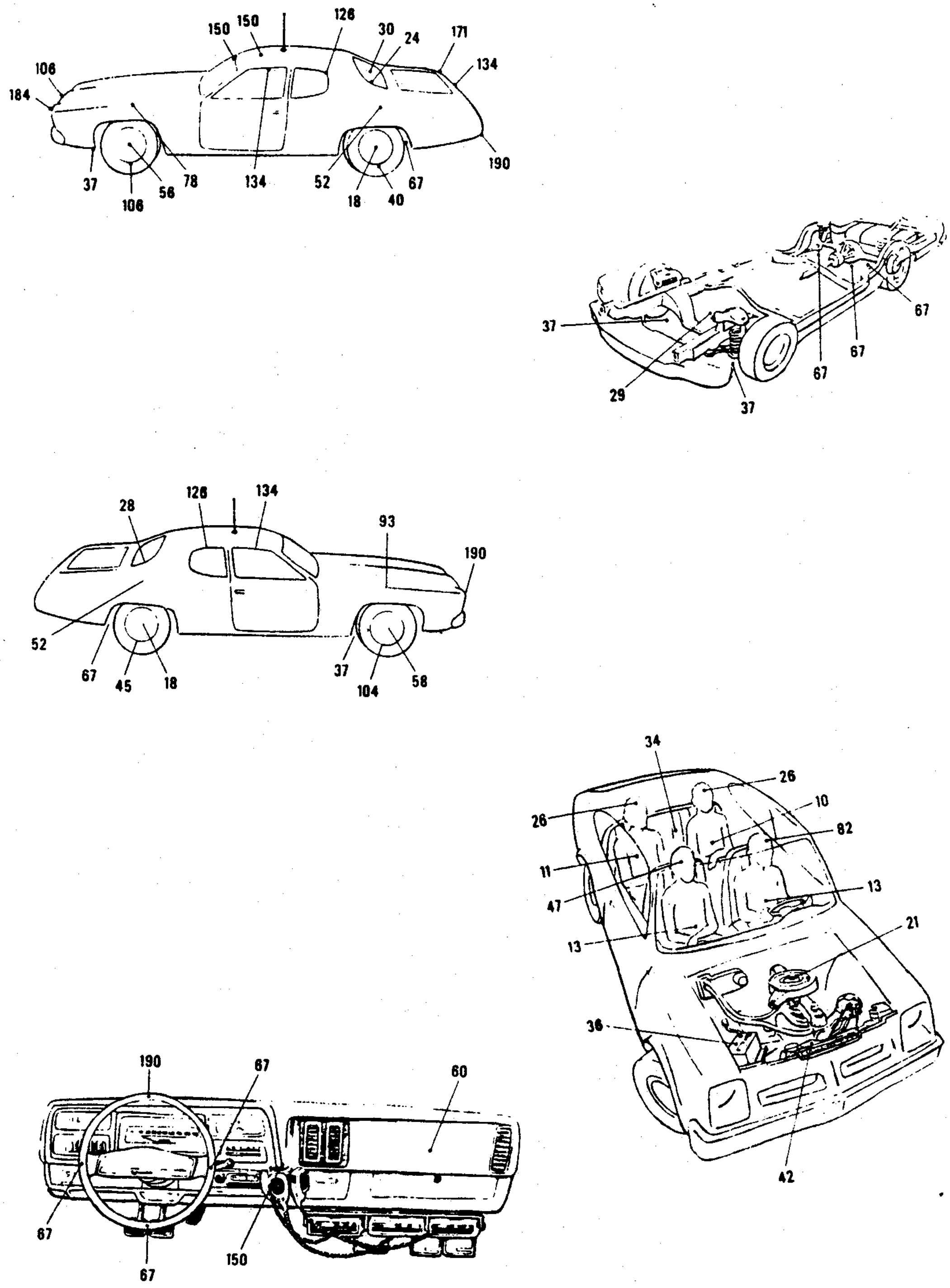


Figure 3.2.2-2: E field measurements, normalized 50th percentile values plotted against frequency. Maxima occur in the AM broadcast and CB (illegal) tests. Source: Reference 36.

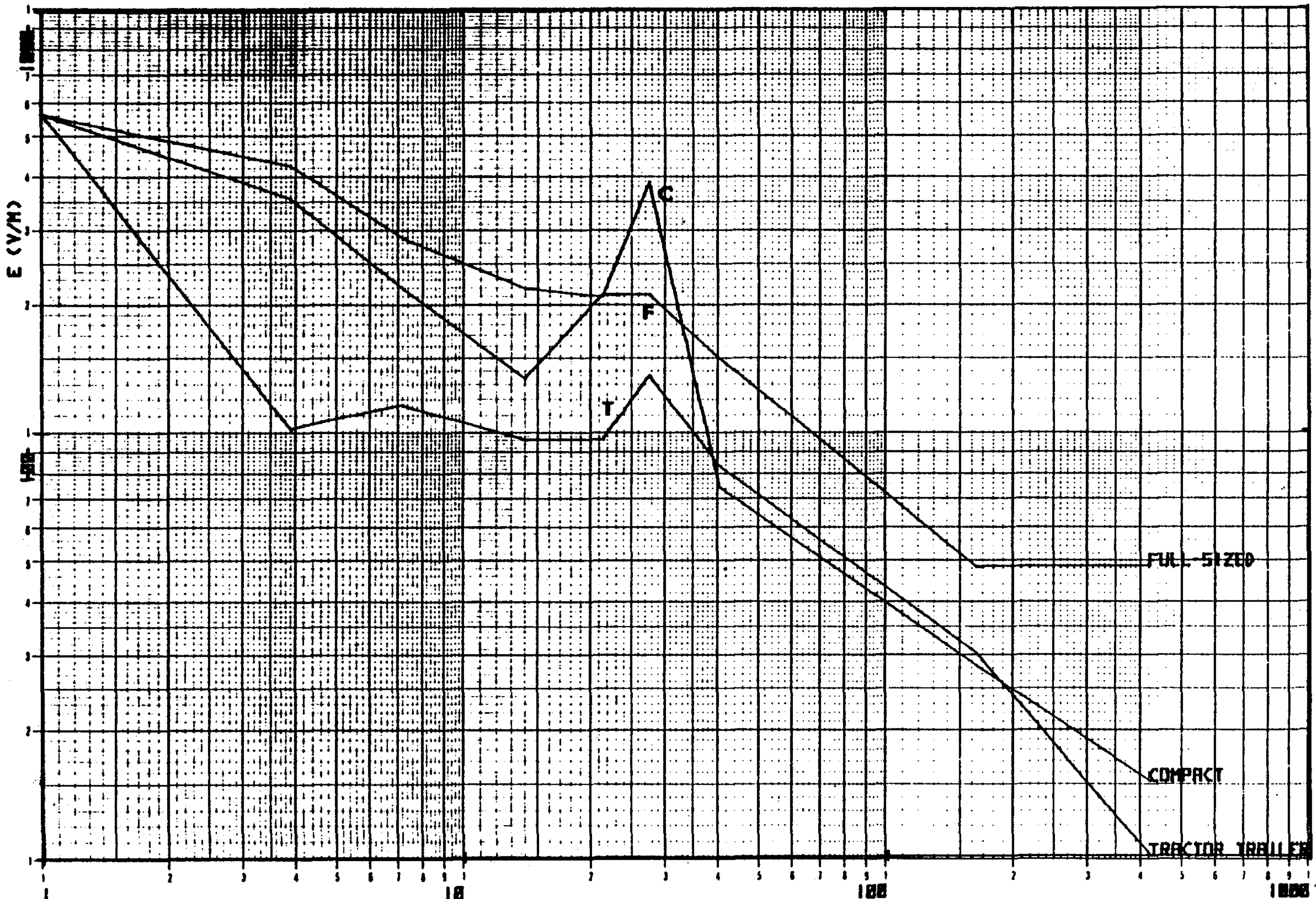


FIG. 39 - E FIELD, WORST CASE, NORMALIZED, 50 PERCENTILE

3.2.3 ELECTROSTATIC DISCHARGE TESTING

TSC and VRTC employed one other technique, known as electrostatic discharge testing (ESDT), to detect any susceptibility of electronic engine controls, including cruise controls, to malfunctions resulting from strong electric fields. ESDT has gained wide acceptance throughout the electronics industry in recent years as a fast, effective way to spot a variety of product malfunctions.

In this technique, a source of high voltage, adjustable up to 25,000 volts, is used to charge a small capacitor. This capacitor is then discharged to ground at or near the device under test. The test apparatus must be designed so that even though the discharge energy is limited (so as to avoid undue hazard to the test technician), the discharge time is very small (a few billionths of a second) and the peak current is very high (more than 50 amperes). The resulting pulse generates a very strong field in its immediate vicinity. The electric field strength near the discharge point approaches one million volts per meter.

As an alternative to a spark discharge, one may also attach a single-turn loop. This accessory produces an intense magnetic pulse field of nearly 1000 amperes per meter at its center.

During the course of tests at VRTC, each of the vehicles was exposed to several hundred spark discharges at various points in its engine compartment and under its dashboard. The discharges were concentrated in the vicinity of the cruise control, its actuator and its wiring harness. Hundreds of magnetic pulses were also applied to the same areas. Figure 3.2.3-1 shows a close-up of a spark about an inch long impinging on the cruise actuator of one of the test vehicles, while Figure 3.2.3-2 shows the magnetic pulse attachment in use.

During this testing, the vehicle was raised on a lift with its wheels free to turn. The transmission was placed in "Drive" and the engine allowed to idle. For a portion of the test, a false speed signal was fed to the cruise control to simulate a condition in which the vehicle was already travelling at sufficient speed for the cruise control to engage.

None of the tested vehicles showed any sign of throttle opening at any time. One of the cruise controls ceased functioning when 25 kV sparks were applied directly to its case and wiring. As a result of these tests, it may be concluded that engine controls of recent design, and cruise controls in particular, are not likely to experience throttle-opening failure modes as a result of exposure to very strong electric or magnetic fields.

Figure 3.2.3-1: Cruise-control actuator subjected to 25 kV sparks from an electrostatic discharge gun. (Photo: VRTC)

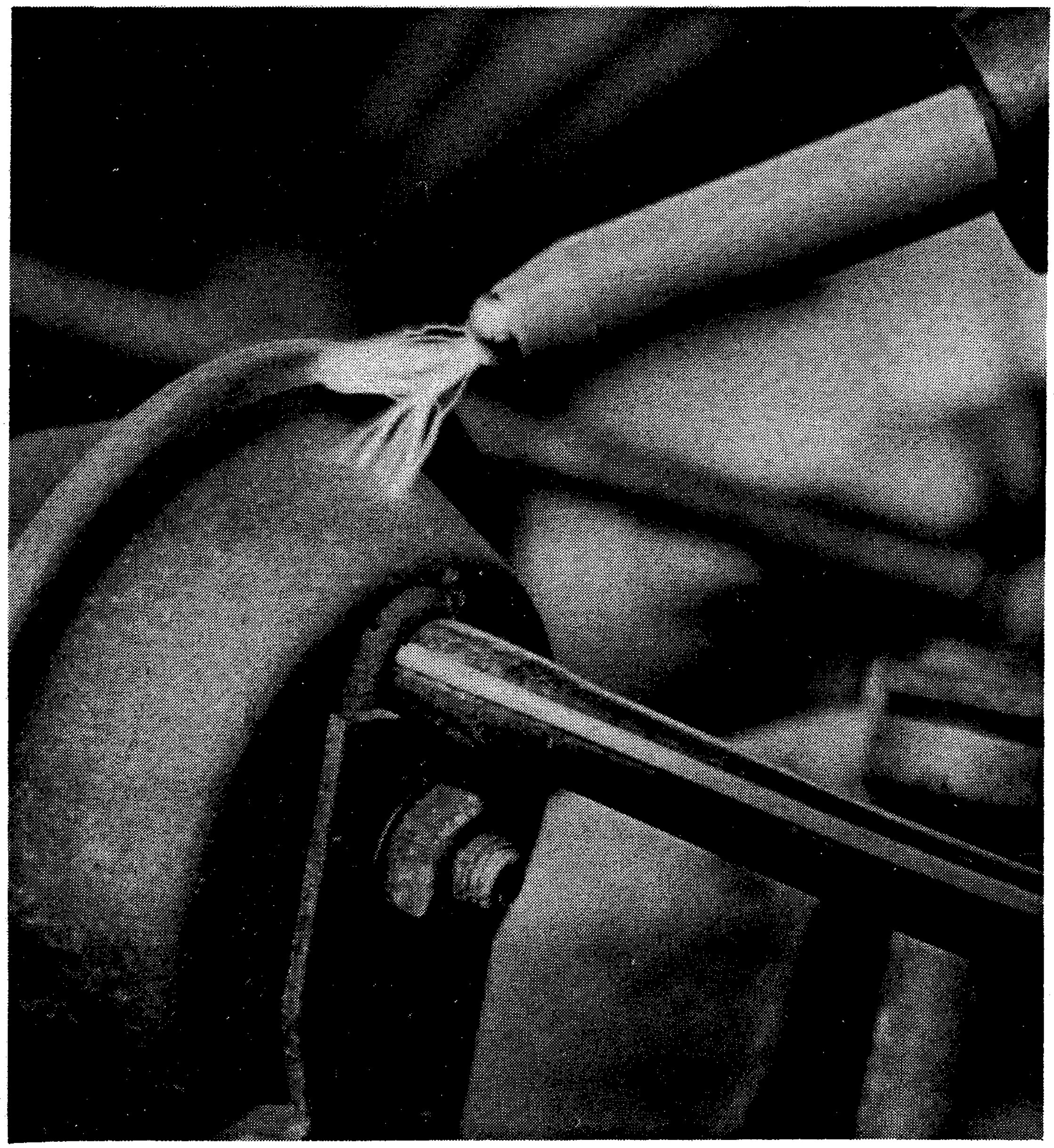
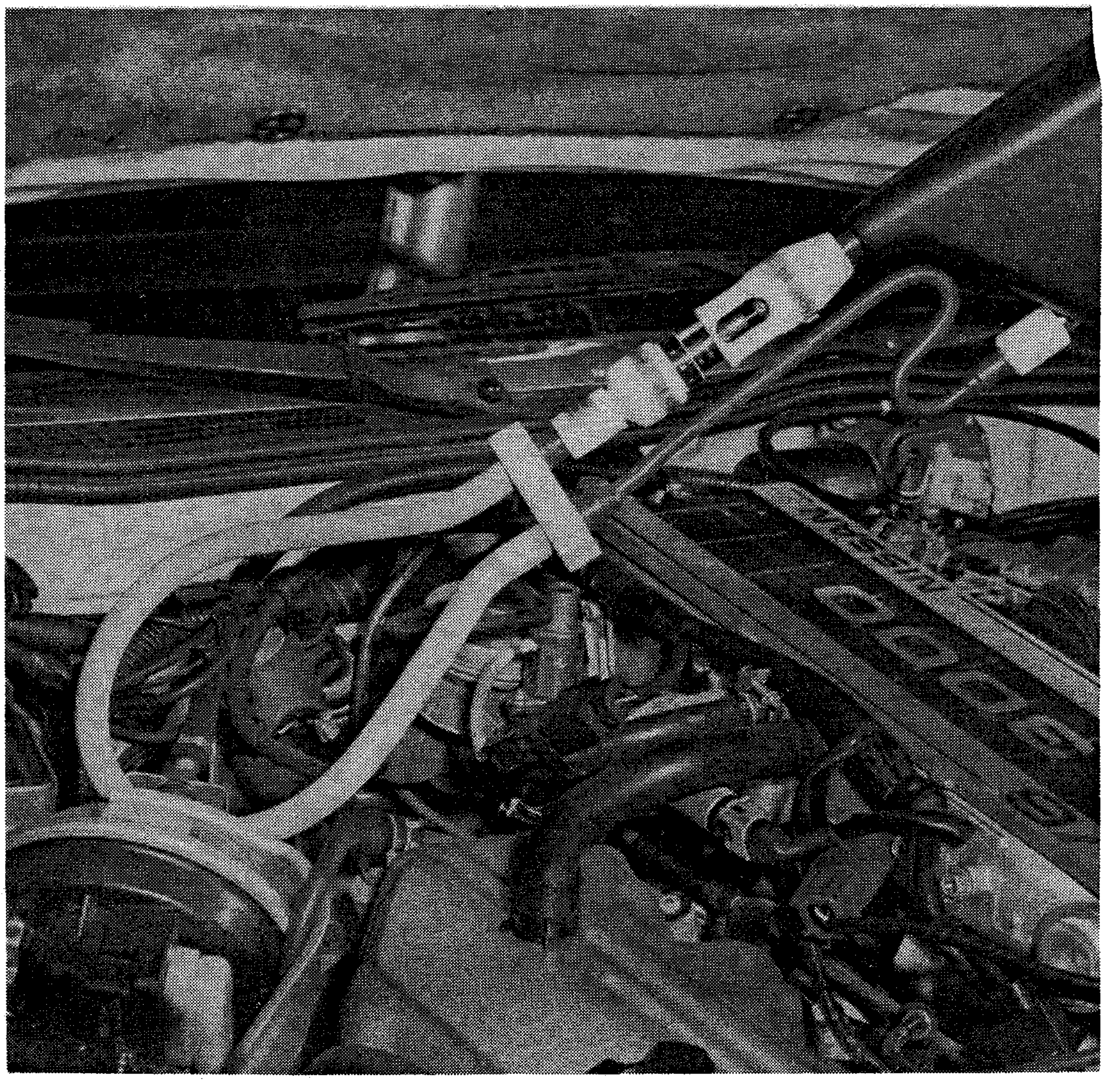


Figure 3.2.3-2: Application of magnetic pulses to cruise-control wiring harness. (Photo: VRTC)



3.3 ERGONOMIC AND BEHAVIORAL FACTORS

Driver error has frequently been alleged to be a factor in SAI. The Panel considered those conditions which might produce or contribute to driver pedal misapplication. Two contributing factors were identified. These are pedal configuration and the startle effect of unanticipated power surges. To fully explain changes in RSAI rates, other behavioral and socioeconomic factors must also be taken into consideration.

3.3.1 VEHICLE/DRIVER INTERACTIONS

The following is a listing of the vehicle characteristics which are thought to influence the frequency of occurrence of SAI. The list is not in any particular order of priority:

- Pedal size, shape, contour, etc.
- Spatial cues to pedal location
- Seat placement
- Pedal placement
- Pedal feel and gain
- Other cues (engine sounds, etc.)
- Ratio of brake torque to WOT engine torque
- Incidence of throttle sticking
- Incidence of erratic idle speed
- Incidence of cruise-control faults
- Incidence of shift-interlock faults
- Incidence of other driver-startling faults
- Presence of an automatic shift lock
- Presence of an automatic transmission

Chapter 7 of Appendix H presents an analysis of these factors for the Audi 5000. Most of these factors could influence frequency and severity of pedal misapplications.

Examination of the RSAI data base shows that almost none of the incidents have occurred in vehicles with manual transmissions. With such transmissions, the driver's feet must be properly aligned with the pedals in order to carry out the relatively complex set of coordinated movements necessary to put the car in motion, thereby greatly reducing the probability of a pedal misapplication. If component malfunctions were the primary cause of SAI, the incidence of problems should be about the same regardless of transmission type, since most of the other powertrain components are common or very similar. This is not the case, and as discussed in Section 3.1.3, no plausible mechanism for automatic-transmission-induced throttle opening was found. This strongly suggests that the major factor in SAI causation is in the driver's interaction with the vehicle controls.

In any situation which requires precise control use, some proportion of errors is to be anticipated. Careful and consistent design can lower the frequency and facilitate the recovery from error.

The driver must be able to distinguish the brake from the accelerator without looking at the pedals. This is accomplished by using sensory cues which are different for each pedal. Chief among these cues are pedal positioning (spatial coding) and "feel" (force-deflection characteristics). Pedal size, shape, angle, surface texture and contour may be used to some extent, although the usefulness of such cues varies with the type of shoe being worn. The direction and curvature of motion required to operate a pedal may also be considered part of its "feel." The presence of other spatial reference points such as the transmission hump can also be important in identifying pedals.

Since brake application can be considered a serial event, the first sensory feedback the driver should receive when mistakenly pressing the accelerator pedal is that the feel is wrong. Typically, the brake pedal can be distinguished from the accelerator because it has a "hard spot" beyond which much more force is required to depress it further. For vehicles in which the difference in feel between brake and accelerator is small, quick recognition of pedal misapplication is more difficult and may not occur until an SAI has ensued.

It is reasonable to expect that control-design ergonomics, which vary from one car to another, are better in some vehicles than others and could account for much of the difference in SAI rates. Consistency between vehicles is important. The vehicle with anomalous control features, however well designed, may contribute to an increase in the frequency of errors for unfamiliar drivers, as discussed below. Beyond a lack of consistency a number of configuration parameters could increase the likelihood of SAI resulting from pedal misapplication. They are:

1. relatively close lateral spacing between brake and accelerator, which increases the likelihood of pedal misapplication and facilitates pressing both pedals with the same foot;

2. relatively smaller vertical spacing between brake and accelerator, which increases the probability of confusion and also facilitates pressing both pedals with the same foot;

3. relatively long brake-pedal travel (soft feel), which reduces the likelihood that the driver will recognize an error in time to avoid an accident and also reduces the amount of brake torque developed at any given value of pedal displacement;

4. relatively powerful engine, which causes the consequences of an error to occur sooner and with greater kinetic energy.

Most of the vehicles which have high RSAI rates have these characteristics.

In a vehicle which combines the first two characteristics, it is entirely possible to place one's right foot so that it presses against both brake and accelerator. The addition of the third characteristic decreases the likelihood that the driver will recognize the misapplication.

TSC measured the pedal separation and force deflection in seventeen vehicles, some of which were characterized by high RSAI rates, while the remainder served as controls. All of the tested vehicles with high RSAI rates moved when the drivers applied light to moderate levels of force (i.e., less than 50 pounds) with the right foot to both pedals simultaneously (tilting the foot slightly to the right). In these conditions the driver reported that the sensation was much like stepping on the brake pedal alone. When sufficient force was applied, these vehicles eventually reached the point at which brake torque exceeded engine torque and deceleration occurred, but the required force was substantially greater than was required for normal stopping.

In contrast, test driving and examination revealed that most vehicles with low RSAI rates had pedal arrangements which made it relatively difficult to exert any substantial force on the accelerator while simultaneously pressing the brake with the same foot.

Previous attempts to analyze the relationships among standard, static pedal-location measurements and RSAI have found positive correlation coefficients for certain measures (References 17, 45). However, the values of the correlation coefficients were not high enough to provide much confidence in the validity of the conclusion that pedal location affected RSAI rates. The test-driving experience suggested that it was not only the static positions of the pedals, but also how they moved with respect to each other and how much engine torque and brake torque were generated at various displacements, that might strongly influence the probability of pedal misapplication. To test this hypothesis, a new procedure was required.

Measuring each pedal characteristic separately would have required fairly elaborate instrumentation, including a chassis dynamometer. After conducting tests on a substantial number of vehicles, multiple-regression analysis of relationships among pedal characteristics and RSAI could then have been undertaken. Such an approach would have fallen outside the scope of this study and needlessly duplicated other research in progress.

Instead, a much simpler technique was devised by TSC in which all of the effects of pressing on the accelerator and brake pedals were combined in a single variable referred to here as "critical vertical offset" (CVO). CVO is defined as the maximum vertical distance between the surfaces of the brake and accelerator pedals at which the vehicle remains stationary for a given force acting on the pedals. Figure 3.3.1-1 illustrates the apparatus used to measure this variable. Appendix G describes the apparatus and measurement procedure in detail and contains a summary of the data for each vehicle tested.

In brief, the measurement procedure involves clamping the apparatus shown in Figure 3.3.1-1 to the brake pedal. A brake-pedal-force transducer is incorporated which shows the applied force on a display placed on the dashboard. The test technician then adjusts the screw mechanism which transmits force to the accelerator pedal to some specified amount of offset, puts the gear selector in drive or reverse, applies a specified amount of force to the apparatus with his foot, and records whether the vehicle remains stationary or not. Tests were conducted at quarter-inch increments of offset ranging from one-half inch to whatever value caused the vehicle to move and at applied forces of 20, 40 and 60 pounds.

It must be recognized that characterizing vehicles according to CVO is a new, experimental approach. At this writing, other researchers in the United States and Canada are conducting similar tests, but none of their results have been published yet.

The scatter plot in Figure 3.3.1-2 summarizes the results of this testing for an applied force of 40 pounds. Lateral pedal separation is plotted on the horizontal axis, while the critical vertical offset appears on the vertical. Cars with high RSAI rates are clustered in the lower left, with lateral separations of about two and one-half inches or less and CVO of about an inch or less. Those with low SAI rates were found to have greater separations on one or both dimensions.

A high CVO and large lateral pedal separation are not the only vehicle characteristics which might contribute to minimizing pedal misapplications leading to unwanted acceleration. Other characteristics, such as the angular placement of the pedals, engine-noise levels, etc., may also provide additional cues to their drivers to help recognize or avoid pedal misapplications. This contention is supported by the fact that some vehicles measured had pedal characteristics which placed them in the lower-left corner of Figure 3.3.1-2, but did not have particularly high rates of SAI reported. The Honda Civic is one example of this. Even though their control designs may be conducive to pedal misapplication, low power or other factors, such as engine noise levels, may keep the consequences of error from occurring before their drivers recognize the problem.

Figure 3.3.1-1: Apparatus used to measure vertical offset shown in close-up. Vertical offset is the distance from the bottom of the plate clamped to the brake pedal to the bottom of the disc pressing the accelerator and is adjusted by turning the pointer knob at the top of the screw. It is shown here installed in a Plymouth Voyager, which has a relatively high offset. The readout display for applied force is placed on the dashboard, out of view in this photograph.

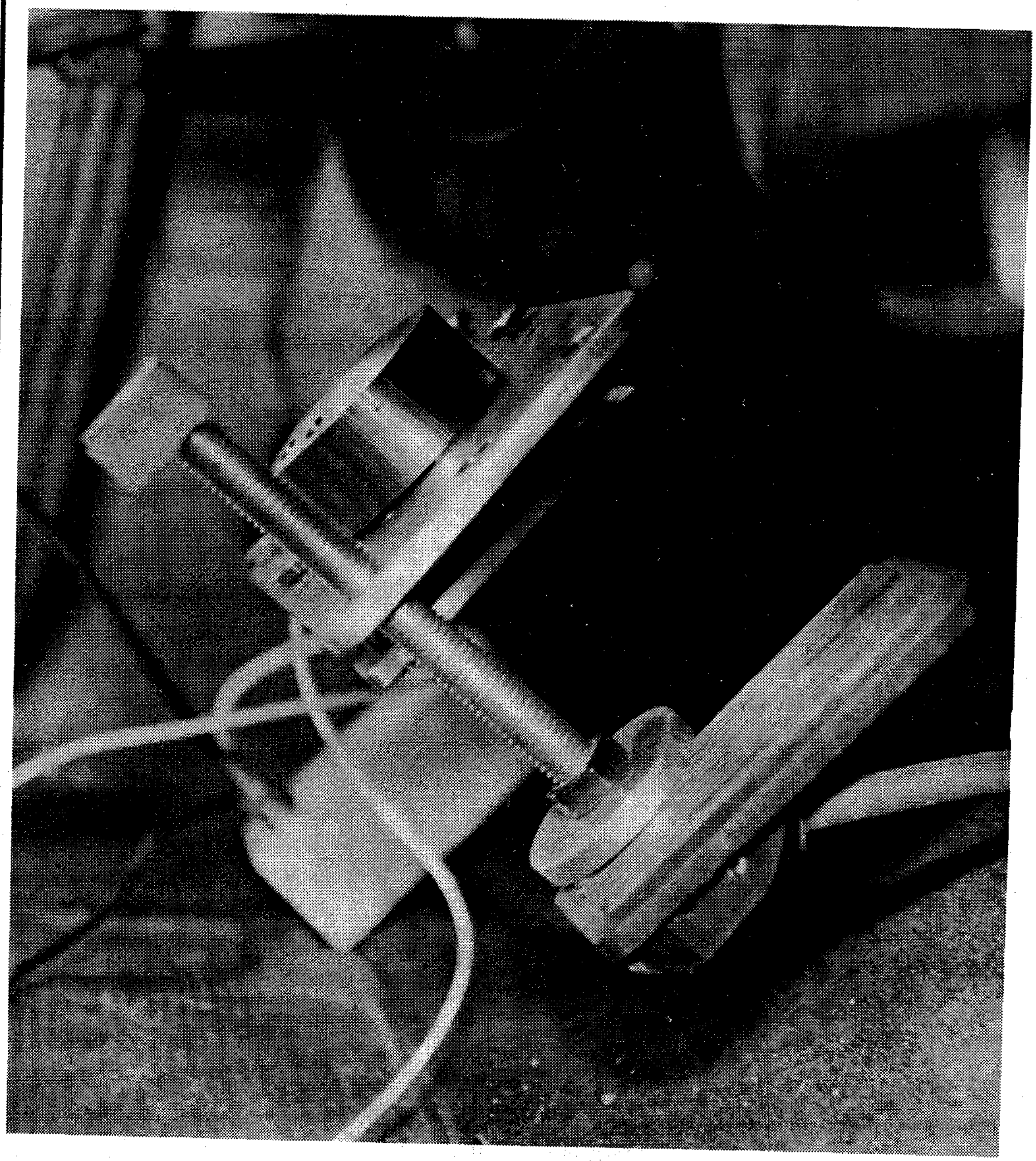
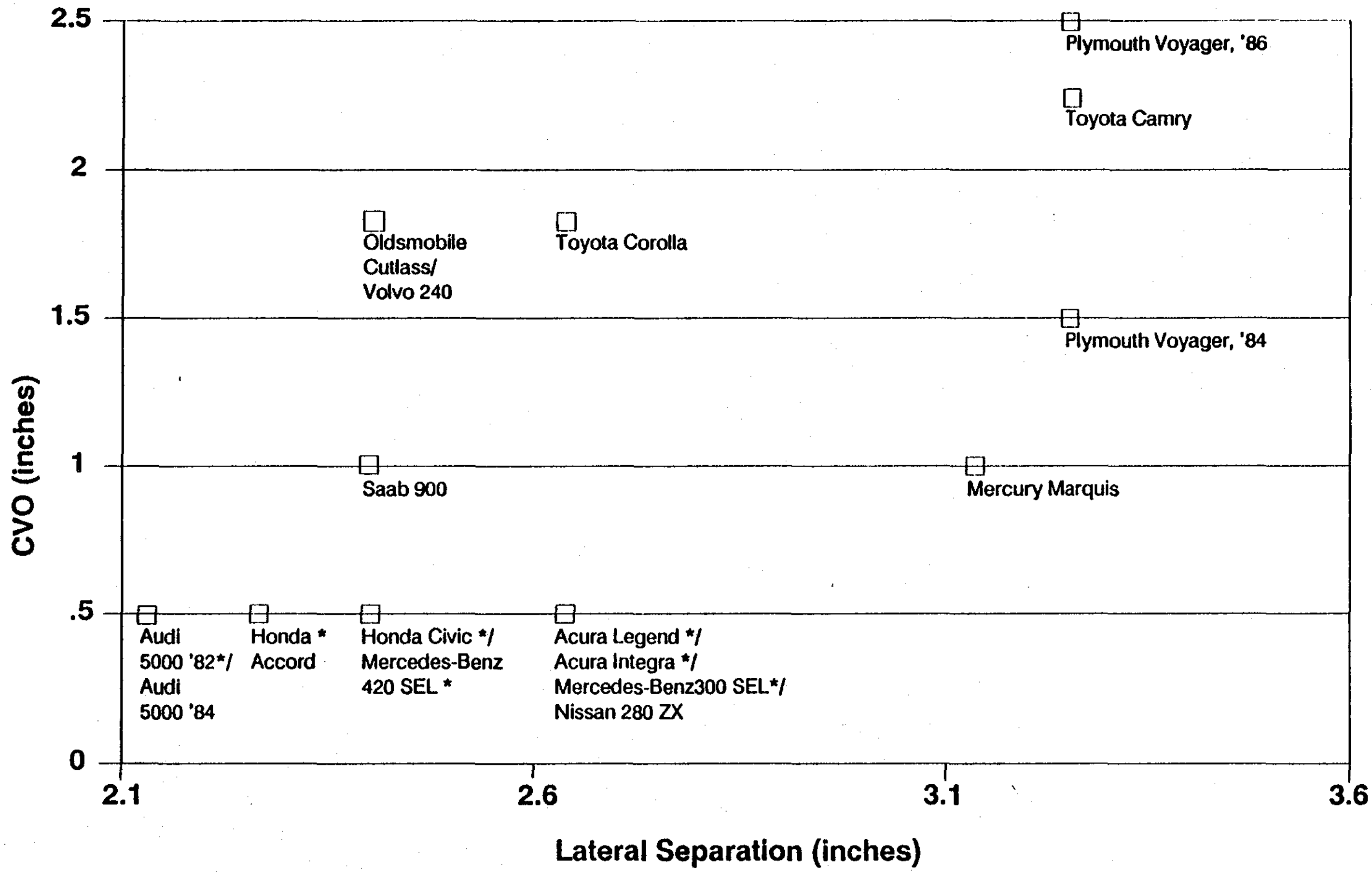


Figure 3.3.1-2: Scatter plot of pedal separation measures for various vehicles. All of the vehicles with vertical offset measurements of less than one inch have above-average rates of RSAI except the Honda Civic. The Mercury Marquis does have an above-average rate, which is not true of the other vehicles with offsets of an inch or more.



Notes: 1. Measurements on this figure were made at 40lbs.

Source: TSC

2. Vehicles marked with asterisks moved at 0.5in. CVO, the lowest value which could be measured with the test apparatus; true CVO would be smaller.

NHTSA is investigating the potential role of pedal design in driver error. Its Office of Research and Development has contracted for a major study of pedal design. This work is currently underway at Texas Transportation Institute and is expected to provide new quantitative measures of the effects of various pedal parameters on the frequency of occurrence of pedal misapplications.

In addition to the vehicle characteristics described above, RSAI rates appear to be influenced by many driver-related variables. It is helpful to divide these into two groups: those which affect the probability of occurrence of an SAI and those which affect the probability of its being reported to NHTSA, which are discussed in Section 3.3.3.

The Panel listed driver factors which might influence the probability of the occurrence of SAI:

Familiarity with vehicle

Driver demographics (age, sex, education, etc.)

Muscle strength

Control use precision

Body dimensions

Life style (mainly as it affects average trip length and the ratio of engine starts to total vehicle miles travelled)

Psychological variables which may influence attentiveness, etc.

Quantitative assessment of the relationship of most of these factors to SAI was not possible because most of these items are not included in the RSAI data.

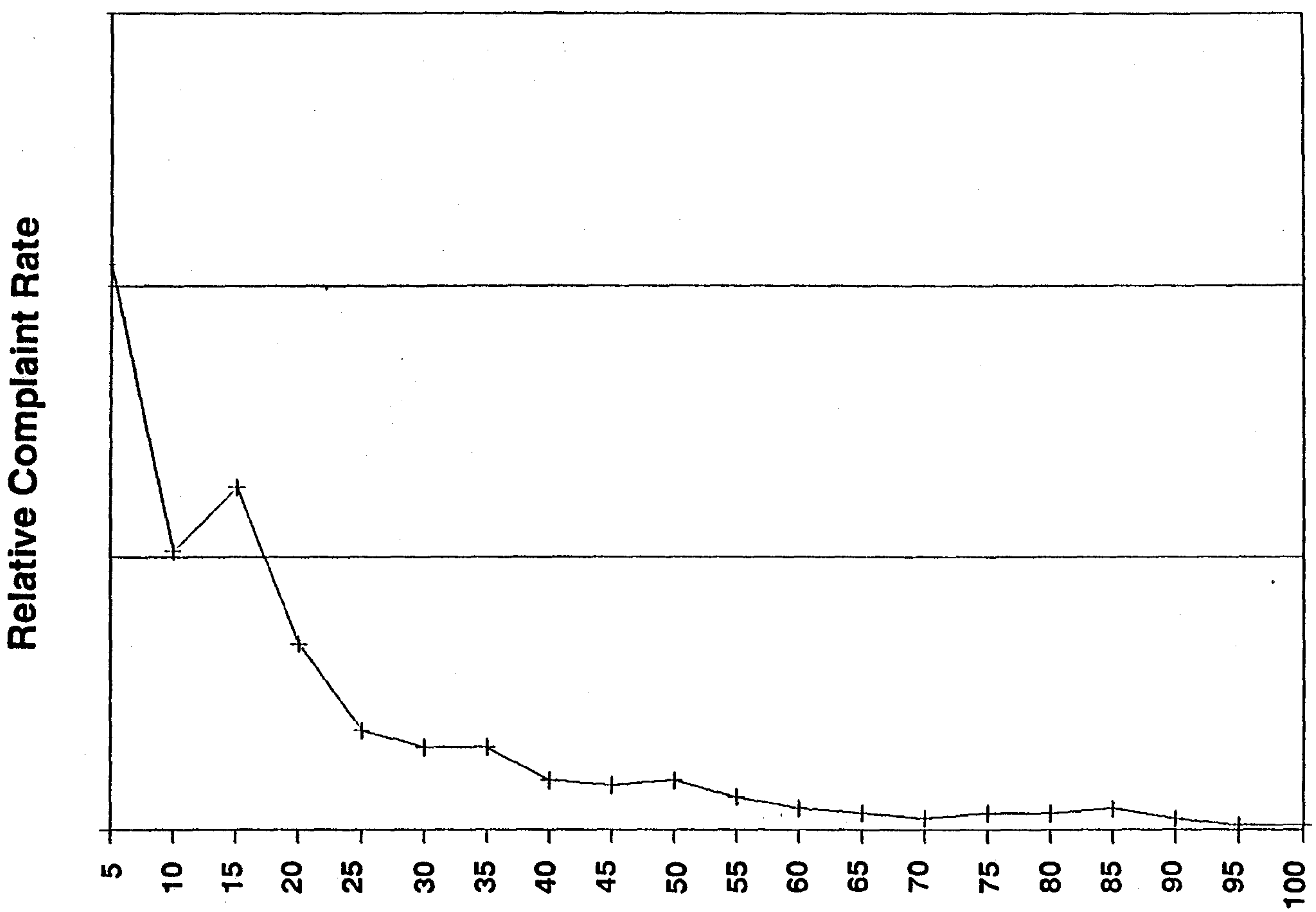
The exception to this is driver familiarity with the vehicle, which can usually be estimated from the odometer readings found in the complaint data. Review of the data recently gathered by NHTSA reveals that the rate of complaints about unwanted engine power falls off precipitously with vehicle milage, suggesting familiarity is strongly related to complaint rate. Figure 3.3.1-3 shows complaint rates as a function of the odometer reading at the time of the incident. (The vehicles included in Figure 3.3.1-3 were selected because they have recently been under investigation by ODI in response to high RSAI rates, which resulted in the generation of a database containing the odometer data.) The extremely steep fall off in complaints with mileage can be taken to indicate that drivers are less likely to misapply pedals as they become increasingly familiar with these cars. This is consistent with the studies cited in Appendix H, Chapter 7, which establish the relationship between driver familiarity and rates for all accidents.

Familiarity may also partially explain why relatively expensive imported cars have much higher RSAI rates than lower-priced imports, many of which have similar pedal characteristics: Most owners of the economy imports have been driving small cars with relatively close pedal spacing for many years. In the luxury car market however, the import share has risen sharply in the 1980's. Thus many of these buyers were making the transition from a large domestic car, with relatively large pedal spacing, to one with an unfamiliar pedal arrangement.

Although little demographic data is available from the ODI data, investigators have used general demographic data on owners to explore the effects of such factors. Attempts to correlate demographic data with RSAI rates have generally not found much statistical significance for most of these variables (References 17, 45). Some analyses have found over-involvement of elderly drivers and/or female drivers. However both of these factors may be related to physiological variables as well as demographics, because both are associated with muscle strength.

Stopping a vehicle with WOT may take a substantial application of force sustained over a period of several seconds. This requirement for sustained high pedal force may increase the likelihood of SAI for weaker drivers under some circumstances. The braking performance data gathered by VRTC show that with WOT, substantial pedal forces (175 pounds or more) are required to achieve maximum deceleration (as noted in 3.1.5 above) for some vehicles. Almost as much force was required to achieve controlled 0.33 g stops (WOT). The tests revealed that the force requirements for the Mercedes, Camaro, and Mercury were sometimes as high as 200 pounds, 170 pounds, and 130 pounds respectively (Appendix E, series 11B tests). Once an SAI has begun and if the throttle remains open, sheer muscular strength can be quite helpful in bringing the car to a stop. Anthropometric data indicate that 50% of all women and a small proportion of weaker men can not provide a brake pedal force of more than 175 pounds for periods of 1 - 5 seconds (Reference 11). Hence, leg strength, rather than age or sex per se, can be an important contributor to the hypothesized SAI (discussed in 3.3.1 above) where the driver applies both pedals simultaneously or where the throttle is being held wide open by some other cause. However, in most instances of application of both pedals, the throttle would be less than fully open and the brake-pedal forces required to stop quickly would be less than those described above.

Figure 3.3.1-3: Unwanted engine-power relative complaint rates (by mileage) for selected vehicles. See footnote.



Miles X 1000 (Source: ODI, Reference 37)

Note: This figure was generated by summing the rates for complaints with odometer readings for the following vehicles: Acura Legends, Audi 5000s, Honda Accords, Nissan ZXs and Mercedes-Benz (all models). Since the curves for the individual models were similar and often overlapping, a confusing figure would result if they were plotted separately. This summation presents a valid measure of the effect of familiarity on complaint rate, but the numeric value of the sum of individual complaint rates is not meaningful. Hence, numbers are not used on the vertical axis.

In addition to familiarity and physical strength, another factor which may influence the likelihood of a pedal misapplication is driver work-load, since unexpected movements of the vehicle may briefly overload and startle the driver resulting in a control error. An example is the jerk that sometimes occurs when a car with high idle speed is shifted into gear without having the brakes firmly set. Such triggering events may play a significant role in explaining SAI. Stimuli resulting from vehicle movement can initiate reflexive responses in the operator. The human "startle" reflex can be characterized as an extensor reflex in which the arms and legs are moved to a more defensive position, sometimes accompanied by rigidity. Closely related is an acceleration reflex in which arms and legs are extended, the toes and fingers spread, in an effort to restore stability to the body. The relevance of such reflexes to this inquiry is that they can be initiated by actions of the vehicle; since they are controlled by the non-cognitive functions of the central nervous system, they may take precedence over conscious efforts to control the vehicle.

In any situation in which a driver is forced to respond to a stimulus more quickly than usual, errors will increase. Thus if the idle speed abruptly and unexpectedly jumps up causing the vehicle to accelerate, the driver, who must respond instantly, is far more likely to partly or entirely miss the brake than when making a planned application.

Two small-scale studies which demonstrate the effects of startling the driver have been published. In the first, conducted by VRTC, 32 subjects, who were not professional drivers, were tested in a 1986 Audi 5000 (Reference 34). The idle stabilizer of the test vehicle was modified so the experimenter could switch on maximum idle speed whenever he desired. One of the subjects did apparently become confused as a result of the excessive idle speed and applied the accelerator rather than the brake, resulting in a 0.6 g acceleration jolt. That driver lost control to the extent that the experimenter terminated the test with the engine-kill switch.

In the second study, conducted by John Tomerlin for *Road & Track*, 130 subjects were tested under three types of driving in three different passenger cars, each of which had been modified so that high idle speeds could be switched on by the experimenter (Reference 33). On two occasions during the reverse-driving test, subjects became confused when the high-idle condition was activated and applied the accelerator when they meant to brake.

A third series of experiments, also conducted by John Tomerlin and as yet unpublished, was completed in June, 1988. Of the 169 subjects tested in a vehicle which was modified so that the experimenter could trigger a WOT at any time, one became confused and unintentionally pressed the accelerator in response to the surprise acceleration (Reference 34).

The reports in the RSAI database frequently indicated that the drivers felt certain they did not press the wrong pedal. This appears to contradict all of this evidence reviewed above demonstrating that the WOT-with-apparent-brake-failure condition characteristic of SAI almost always requires a pedal misapplication. Human-factors psychologists have offered the following hypotheses, either alone or in combination, to explain how sober, honest drivers might have arrived at their recollections of an incident:

1. In some small proportion of the incidents, a WOT condition was caused by a malfunction of the vehicle. The driver correctly applied the brakes, but mistakenly described the increased stopping distance caused by WOT as "brakes not working." Wherever there is physical evidence of such a malfunction, pedal misapplication was probably not the initiating factor.

2. For those vehicles in which it is possible to depress both pedals with the same foot and cause vehicle movement (most vehicles with high SAI complaint rates fall into this category), the "feel" of pressing both pedals is similar to that of pressing the brake pedal alone.

3. When the driver becomes heavily over-loaded with information to process and motor responses to initiate actions, as in an out-of-control situation, it is possible that verification by neural feedback to the effect that the intended event has really occurred, may become a low-priority activity for the brain. That is, when the brain is too busy, it simply assumes the muscles are performing as desired and ignores or misinterprets the feedback provided by the vehicle's movement. For example, if neuro-muscular feedback indicates that a pedal is depressed, the brain assumes it is the intended pedal even when the opposite may be the case. (The more subtle the difference in "feel" between the pedals, the more likely this kind of error.) In other words, the brain occasionally remembers the neuro-muscular commands it gave rather than the responses made to those commands.

4. In a small number of the accidents, drivers suffered concussion or other head trauma. Such injuries may be accompanied by retrograde amnesia, a condition of memory loss where the events of the accident and others immediately preceding it are at least temporarily forgotten. The natural tendency is to assume that during these lapses, one did what one normally does, for example, pressing the brake pedal to stop the car.

5. Subconscious memory alteration in defense of the ego may occur in some drivers who have made errors resulting in accidents.

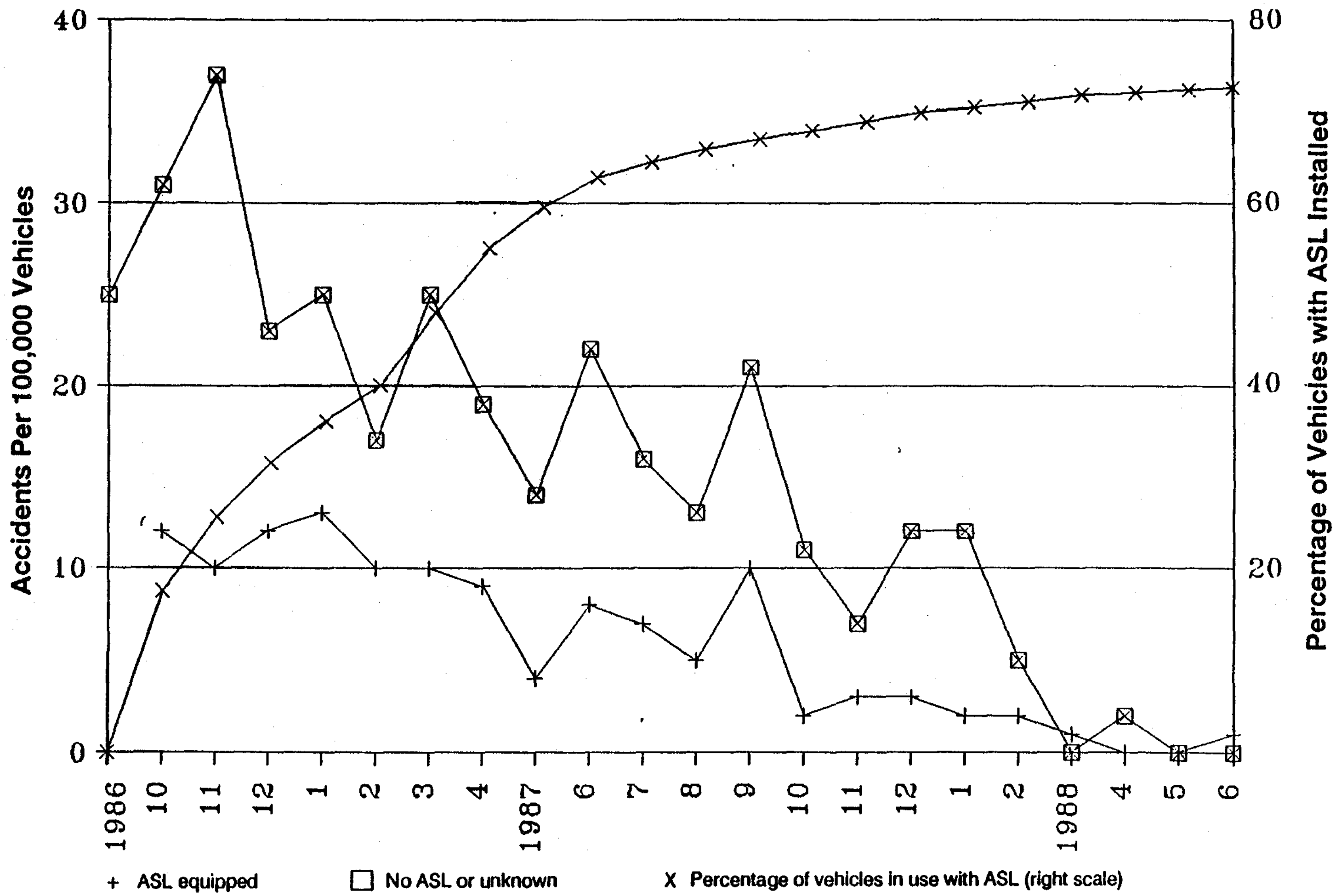
3.3.2 AUTOMATIC-SHIFT-LOCK EFFECTS

Support for the pedal-misapplication hypothesis is provided by recent statistical data showing that the rate of SA accidents has dropped quite substantially for vehicles with automatic shift-locks (ASL) relative to identical models that lack them. Drivers in ASL-equipped vehicles must positively locate the brake pedal before shifting out of "Park" and perform this task quite frequently. This required repetition speeds the development of appropriate pedal use procedures. This reduces the chances for subsequent error. (Second-generation ASLs, which prevent shifting from "Neutral" as well as "Park" are expected to result in further reduction in RSAI.) Figure 3.3.2-1 shows the complaint rates month-by-month for the Audi for two years. The cumulative complaint rates (9/86 through 11/88) for the ASL-equipped cars are about 60% lower than the corresponding rates for the non-ASL cars.

The only other vehicle on which an ASL retrofit has been conducted is the Nissan ZX. Data for these cars appear in Figure 3.3.2-2.

Due to delays in the reporting of incidents, both of the following figures are subject to continuing revision.

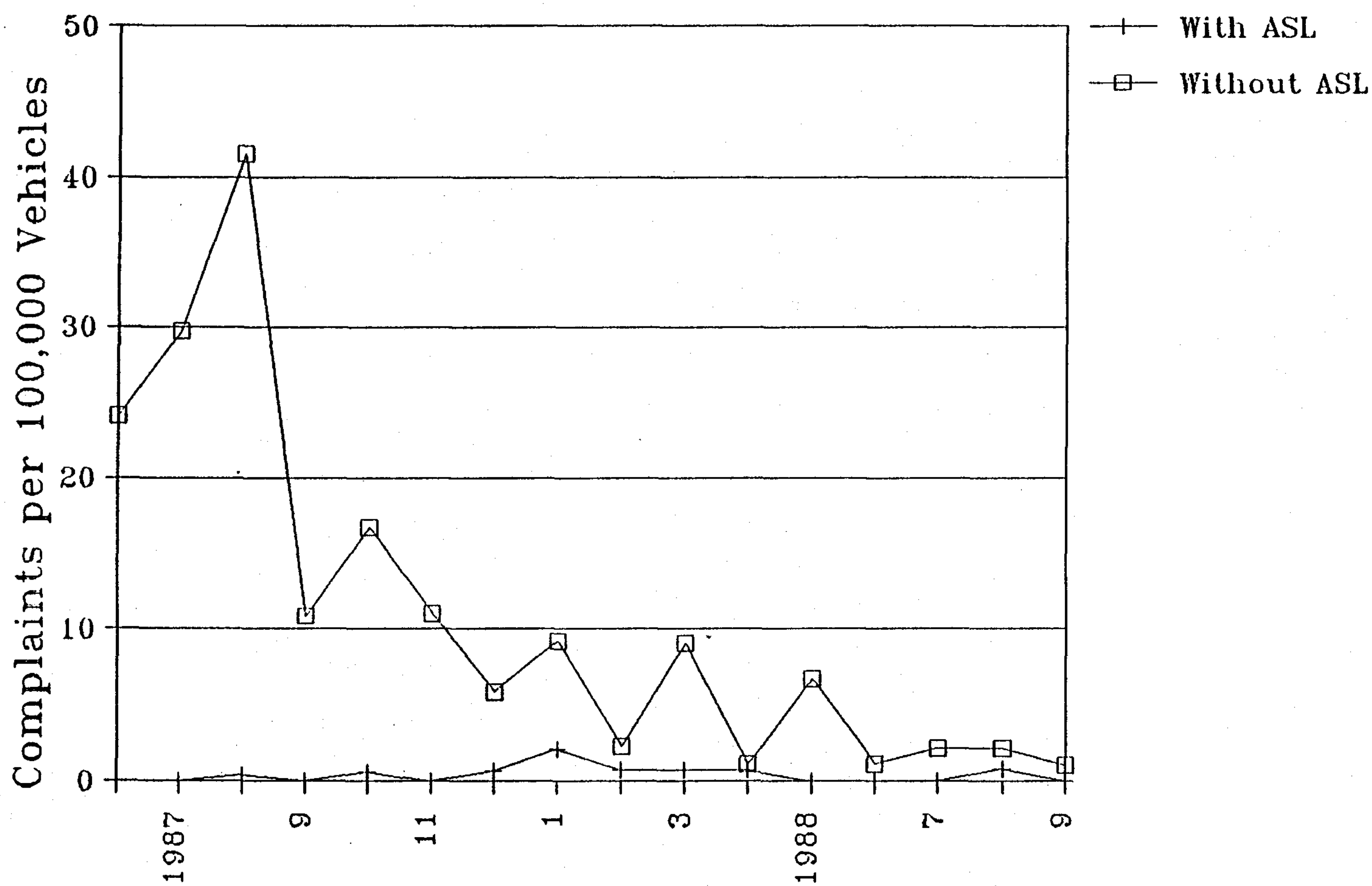
Figure 3.3.2-1: Comparison of RSAI for Audi 5000 cars with and without the ASL installed.



Source: ODI Audi Database

Note: Percentages of vehicles with ASL are ODI estimates for the period 9/86 through 2/87

Figure 3.3.2-2: RSAI for the Nissan ZX models with and without the ASL installed.



Date of Report

Source: ODI database

Notes: Vehicle populations estimated prior to 9/87 and for 9/88

3.3.3 REPORTING FACTORS

The basic data available to the media and the public have been complaint data. The likelihood that a driver will report an incident is usually influenced by his or her perception as to its cause, because in most cases, there is no physical evidence. The following are among considerations which can affect the probability of an SAI being reported to NHTSA and/or the manufacturer as an SAI complaint:

> Severity of the incident
>
> Publicity and media coverage of SA problems in general
>
> Publicity and media coverage of SA problems of the particular vehicle in question
>
> Existence of a recall campaign for SA problems
>
> Existence of an organization devoted to SA problems in a particular vehicle and related class-action law suits
>
> Income and education levels of the driver
>
> Driver's awareness of the term "sudden acceleration"
>
> Driver's expectations about the reliability of the vehicle
>
> Incidence of non-SA malfunctions in the car
>
> Warranty coverage

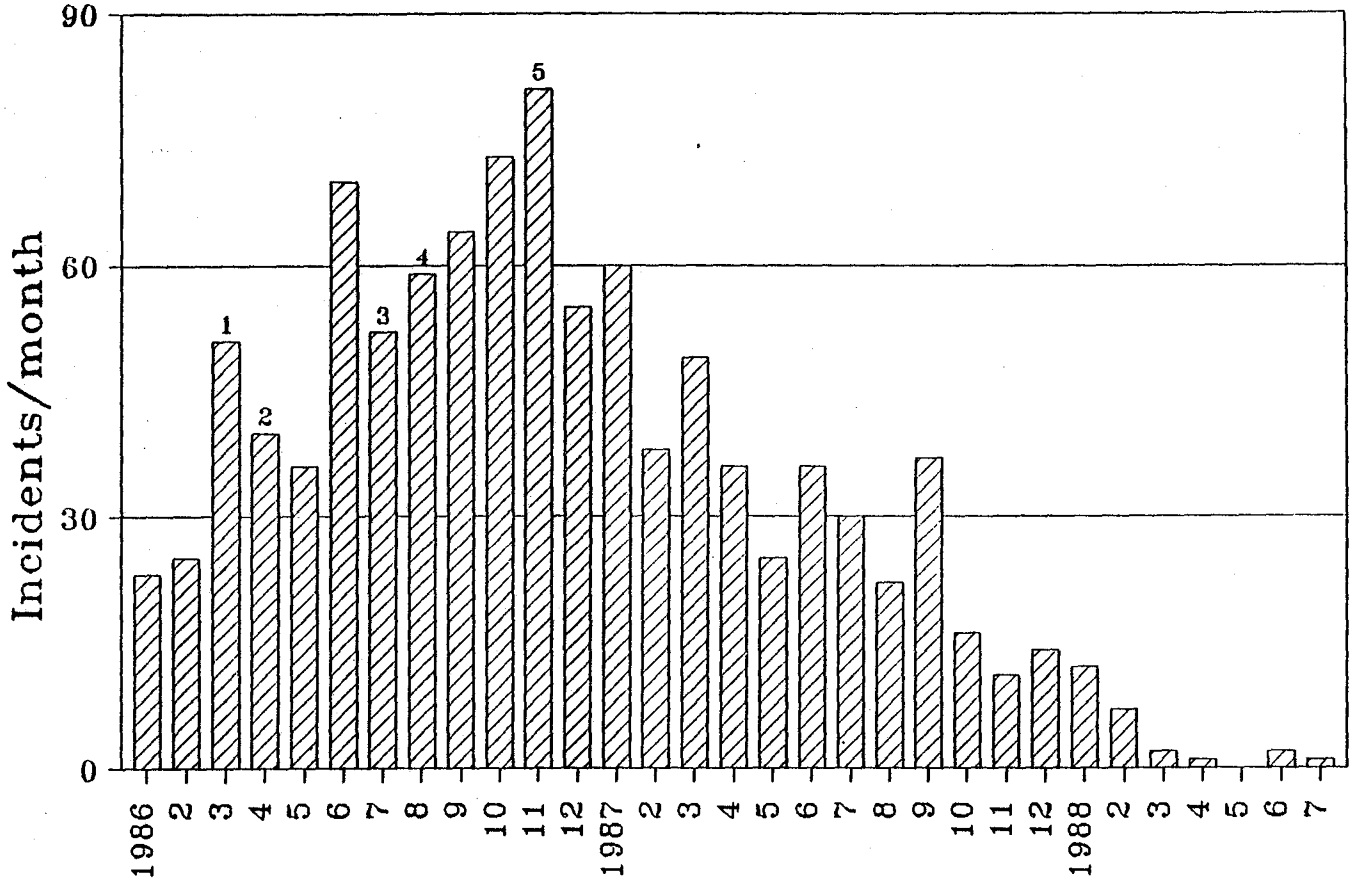
Some bias in the comparative RSAI rates among vehicle makes could result from differences in the socioeconomic status of owners or drivers. Wealthier, better-educated drivers may have a higher propensity to make their sudden-acceleration accidents known to the government and the media, which could lead to higher complaint rates for expensive cars. Survey research has shown that income and education are strongly correlated with both the propensity to complain and the propensity to contact a government official about a complaint (References 3, 4, 18, 47).

The many vehicle, driver, and other factors which impact the RSAI rate make the comparisons between different vehicles or even among vehicles at different times very difficult. It would be somewhat misleading to compare the RSAI rate for a model which has been in the fleet for only a year with one that has been there for several years, although the distortion would be moderate since most complaints occur early in the life of a vehicle.

The true number of events which could lead to an SAI may be substantially larger than the number of SAI reports, because many drivers who make pedal misapplications perceive them as such and do not register complaints. However, when the media focus on the matter and suggest that there are unknown mechanical or electronic causes, the perceptions of some incident-involved drivers may be modified and cause them to conclude that their vehicles must be at fault. In the case of the Audi-5000 the peak complaint rates coincide with discussions of the problem on network television (see Figure 3.3.3-1). Survey research has shown that a consumer who believes a manufacturer has intentionally covered up a product defect is twice as likely to complain as one who does not hold that belief (Reference 20).

This characteristic of consumer complaint data related to SAI does not logically apply to complaint data for other motor-vehicle safety problems. In other areas, there are usually obvious malfunctions which are more easily verified by investigators, so that changes in consumer perception are less likely to be a problem.

Figure 3.3.3-1: RSAI by month for the Audi 5000 with major media coverage events noted.



Source: ODI Database and Reference 46

1. CAS, NYPIRG et al petition NHTSA. Petition receives wide media coverage in New York.
2. Audi Victims Network formed.
3. Audi shift-lock recall announced.
4. NHTSA opens formal investigation of SAI in Audi 5000
5. CBS's "60 Minutes" episode on SAI in the Audi 5000.

3.4 TECHNICAL SUMMARY

By definition, SAI can occur only when the engine is producing at, or nearly at its maximum power, and when the driver intends to stop but can not. In the absence of a malfunction creating an unintended entrance path for combustion air (which should be readily obvious to the SAI investigator), opening the throttle is the only action which can produce high power. Other types of malfunctions which cause significant amounts of unwanted engine power resulting in modest amounts of acceleration do not fall within the definition of SAI unless they startle the driver into a pedal misapplication.

Only the driver's foot or the cruise control can move the throttle to the wide-open position, although binding in the throttle or its linkage, floor-mat jams, etc. may hold it there. In certain models or families of models sharing a common fuel-control system, throttle sticking has been verified as the cause of a number of incidents.

No mechanism for temporary, self-correcting brake failure of any relevance to SAI was found to exist. However, for certain types of vehicle designs, stopping distances were substantially increased with the throttle held wide open (see Section 3.1.5). Further, under WOT conditions, the braking forces required to stop the vehicle increase significantly. This increase may lead drivers to believe the brakes have failed. For some very powerful, rear-wheel-drive cars, weaker drivers may be unable to apply sufficient pedal force to stop against WOT.

For SAI in which there is no evidence of throttle sticking or cruise-control malfunction, the inescapable conclusion is that these definitely involve the driver inadvertently pressing the accelerator instead of, or in addition to, the brake pedal.

While the evidence suggests that most SAI probably involve the driver unintentionally pressing the accelerator when braking was intended, it is important to consider why the reported frequency of these incidents varies so widely among different models. Vehicle-design factors, especially pedal position and pedal feel, are suggested as very important explanatory variables.

Unlike other types of safety defects, the occurrences of which are usually verifiable through physical evidence, decisions to register SAI complaints are matters of drivers' perceptions. Their perceptions may be influenced by a host of intervening variables. In many instances which could lead to an SAI, the driver realizes that pedal misapplication has occurred and never reports the matter. However, if the driver does not recognize the error, a vehicle malfunction may be assumed and reported as such.

From the human factors point of view, the problem is that the design and functioning of the vehicle interact with the driver's attempts to control it in unintended and unanticipated ways. It is a generally accepted goal that vehicles should be designed so that they minimize the likelihood of control-use error and maximize the probability of recovery from such errors without harm. Drivers vary in their abilities and consistencies in sensing such variables as pedal feel and location. Furthermore, while a driver may be able to perform a task correctly thousands of times, such as applying the brake pedal , occasional lapses may still occur. Vehicle design strongly influences the frequency of these errors. Vehicles with high RSAI rates share pedal configurations and force-deflection characteristics which could be conducive to pedal misapplication.

APPENDIX A

Curricula Vitae
Of Panel Members

John W. Adams (M'83, SM'83) received the B.E.E degree in electrical engineering from Georgia Institute of Technology in 1954 and the M.S.E.E. in electrical engineering from North Carolina State University in 1964.

He worked at Western Electric Company and Bell Telephone Laboratories from 1954 to 1960 with an interruption for military service in the U.S. Army Signal Corps. He has worked at the National Institute of Standards and Technology in Boulder, Colorado since 1964. He has worked in microwave and millimeter wave power measurements, antenna measurements, and since 1972, in electromagnetic interference measurements.

Mr. Adams is active in the IEEE EMC Society and is Chairman of the 1989 EMC Symposium to be held in Denver, Colorado, in May of 1989.

DAVID M. FISCHER

Mr. Fischer is a member of the Electronic Systems Section of Arthur D. Little, Inc. He is an electronic and electromechanical circuit and system designer with particular expertise in discrete component and integrated circuit electronic design, switching circuitry, digital logic, and machine design, as well as feedback and control theory.

Some of Mr. Fischer's accomplishments include:

- Design and implementation of a 150W switching power supply for worldwide use in data communications equipment
- Design of a line operated switching motor controller for sliding doors
- Advising clients on implications of UL, CSA, VDE and FCC standards
- Review for the U. S. Navy of a torpedo electric power system
- Review of power supplies for aircraft fuel management systems
- Redesign of an electronic high power furnace ignitor
- Review and redesign for two TWT power supplies including magnetics
- A study of BDC motors and associated controls for a major automotive manufacturer
- Evaluation of a novel concept for a high energy automotive ignition system
- Cost analysis of competitive power supplies for a major personal computer manufacturer
- Review of power supply manufacturing capabilities for a major manufacturer of electronic equipment
- Design of power systems and support logic for a 4 kW rotating reciprocating engine for an aerospace cryogenic cooler
- Support and redesign of an electronic fluorescent lamp ballast to reduce cost and complexity
- Design of a proprietary flashtube illumination system power supply for a medical diagnostic instrument manufacturer.

DAVID M. FISCHER (continued)

Prior to joining Arthur D. Little, Inc., Mr. Fischer was a Principal Engineer with Codex Corporation. He was responsible to the Director of modulation products for the review of hardware and as a design consultant. Previously he was a member of the power supply group and manager of modulation product support.

From 1974 to 1975, Mr. Fischer was an independent hardware consultant in the field of electronics and from 1972 to 1974, he was employed by the C. S. Draper Laboratory, where he was involved in the design of a new line of high density, hydraulic motors for use in automated assembly machinery.

Mr. Fischer received his S.B. in Electrical Engineering and his S.M. in Mechanical Engineering from the Massachusetts Institute of Technology.

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JOHN B. HEYWOOD

Professor of
Mechanical Engineering

[redacted] [redacted]

DEGREES:	B.A.	Cambridge University, England	1960
	S.M.	Massachusetts Institute of Technology	1962
	Ph.D.	Massachusetts Institute of Technology	1965
	Sc.D.	Cambridge University, England	1984

FIELDS: Engines, Combustion, Thermodynamics, Fluid Mechanics

PROFESSIONAL EXPERIENCE:

1976 to present	Professor of Mechanical Engineering, M.I.T.
1972 to present	Director, Sloan Automotive Laboratory
1970 - 1976	Associate Professor of Mechanical Engineering, M.I.T.
1968 - 1970	Assistant Professor of Mechanical Engineering, M.I.T.
1967 - 1968	Group Leader, Central Electricity Generating Board, Leatherhead, United Kingdom
1965 - 1967	Research Officer, Central Electricity Generating Board
1964 - 1965	Research Associate, Mechanical Engineering Department Massachusetts Institute of Technology
1963 - 1965	Lecturer, Northeastern University, Boston, MA

PROFESSIONAL ACTIVITIES:

Associate Fellow:	American Institute of Aeronautics and Astronautics
Member:	American Society of Mechanical Engineers
Member:	The Combustion Institute
Fellow:	Institution of Mechanical Engineers
Fellow:	Society of Automotive Engineers
Member:	Editorial Advisory Board: Combustion and Flame
Member:	Editorial Advisory Board: Progress in Energy and Combustion Science
Member:	Editorial Advisory Board: International Journal of Vehicle Design

AWARDS:

1985	American Society of Mechanical Engineers Freeman Scholar for 1986
1984	Recipient of Society of Automotive Engineers' Horning Memorial Award for best paper on fuels and engines
1982	Elected a Fellow of Society of Automotive Engineers
1981	Recipient of Arch T. Colwell Merit Award, Society of Automotive Engineers, for an outstanding contribution to the technical literature
1980	Recipient of Society of Automotive Engineers Award for an outstanding Oral Presentation
1976-77	Richard Mellon Overseas Fellow at Churchill College, Cambridge University, England
1973	Recipient of Arch T. Colwell Merit Award, Society of Automotive Engineers, for an outstanding contribution to the technical literature
1971	Recipient of a Ralph R. Teeter Award to outstanding young engineering educators by Society of Automotive Engineers
1969	Awarded Ayreton Premium, Institution of Electrical Engineers, for paper in Proc. I.E.E.
1964	Elected member Sigma Xi
1960	Fulbright Travel Scholarship
1957-60	Open Major Scholarship, Gonville and Caius College, Cambridge University

RESEARCH ACTIVITIES:

Professor Heywood's research interests lie in the areas of thermodynamics, combustion, energy, power and propulsion. He has been active in the field of open-cycle MHD power generation. During the past two decades, his research activities have centered on the operating and emissions characteristics, and fuels requirements, of automotive and aircraft engines. A major emphasis has been on developing models to predict the performance, efficiency and emissions of spark-ignition, stratified charge, diesel and gas turbine engines, and in carrying out experiments to evaluate the validity of these models. He is also actively involved in technology assessments and policy studies related to automotive engines, automobile fuel utilization and the control of air pollution from mobile sources.

He is currently Director of the Sloan Automotive Laboratory in the Mechanical Engineering Department and is the Coordinator for Transportation Programs in the Energy Laboratory, at M.I.T.

CONSULTING:

Professor Heywood has been or is now a consultant for the following organizations:

AVCO Systems Division, Bendix, Broken Hill Proprietary Co., Ltd., Coordinating Research Council, Cummins Engine Co., DeLorean Motor Co., Department of Transportation, Edison Electric Institute, Ford Motor Company, General Dynamics, Jaguar Cars, A.D. Little, Inc., Mobil Research and Development Corporation, National Academy of Sciences, National Bureau of Standards, Northern Research and Engineering Corporation, Office of Technology Assessment, O'Melveny & Myers, Pratt & Whitney Aircraft, Thermo Electron Corporation, Turbodyne Corporation, U.S. Department of the Treasury, U.S. Post Office.

LOUIS F. KLUSMEYER
Senior Research Scientist
Vehicle Research and Development
Engine and Vehicle Research Division

B.S. in Industrial Arts/Physics, Western Illinois University, 1966
Graduate Studies in Business Administration, Western Illinois University, 1968-72
Registered Professional Quality Engineer

Mr. Klusmeyer's technical career began in the U.S. Navy as a nuclear power plant operator, qualified on both aircraft carrier and destroyer nuclear power plants. While in the Navy, he also served as an instructor for nuclear power plant trainees at the destroyer prototype nuclear power plant, specializing in electronic equipment.

After leaving the Navy, Mr. Klusmeyer joined Motorola, Inc., where his experience included test equipment design, vendor investigation, short- and long-term component testing, component failure analysis, and design of new component test methods. Mr. Klusmeyer was selected as manager of the Incoming Quality Assurance department for a new Motorola consumer products plant in Texas and was manager of that department for 3 years prior to joining Southwest Research Institute.

At Southwest Research Institute, he has performed engineering and quality assurance functions for inspections of commercial nuclear power plants and supported the impact sled test facility and other programs on vehicle accident data acquisition. Mr. Klusmeyer participated in an Army program to install and test small diesel engines in the M151A2 1/4-ton truck and to test and evaluate the White stratified-charge engine in the same vehicle. He also served as technical manager for the DOE Electric Vehicle Demonstration Program and managed truck component environmental test programs, motor home compliance testing for FMVSS requirements, and a project to analyze and measure vehicle seat comfort.

Mr. Klusmeyer has managed programs that involved FMVSS compliance testing, fault analysis, and in-service testing of foreign medium- and heavy-duty trucks from several manufacturers. During these programs, he visited large numbers of truck dealers, distributors, and fleet users; was involved in in-service truck tests in nine states; and traveled to customer-designated sites to provide engineering input required for fault analysis and repair or design change. He managed a test and analysis program for transit coach anti-lock brakes and was program manager for a study of truck and bus fleet needs in the field of vehicle and engine diagnostics. Recently, he served as manager of projects that investigated currently available on-board data recorders, selected those most suitable for monitoring anti-lock braking performance, installed the selected recorders on anti-lock-equipped truck tractors, and monitored the performance of the recorders and the anti-lock brake systems.

PROFESSIONAL CHRONOLOGY: U.S. Navy 1958-65; Motorola, Inc., consumer and automotive products divisions, 1966-76; Southwest Research Institute, senior research scientist, 1976-.

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RAYMOND MAGLIOZZI

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Good News Garage
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B.S. Humanities & General Science, MIT, 1972

After graduating from MIT, Raymond Magliozzi opened Hacker's Haven in Cambridge, a do-it-yourself garage. He taught courses in the fundamentals of auto repair there as well as at the Cambridge Center for Adult Education.

Hacker's Haven evolved into Good News Garage, a ten-bay facility staffed by professional mechanics.

In 1976 together with his brother, Tom, Mr. Magliozzi created the weekly radio program, "Car Talk." In 1988, the program was syndicated for broadcast by National Public Radio affiliates around the country.

GARY L. STECKLEIN
Director
Department of Vehicle Systems Research
Engines, Emissions and Vehicle Research Division

B.S. in Mechanical Engineering, Kansas State University, 1974
M.S. in Business Administration, University of Texas at San Antonio, 1985
Registered Professional Engineer, State of Texas

Gary Stecklein began his professional career as a design engineer with Deere & Company in 1974. In this capacity he designed components for prototype industrial crawler loaders and dozers, including structural and hydraulic components.

Mr. Stecklein was promoted to product engineer for Deere & Company in 1977. As product engineer he determined engineering specifications for, and performed feasibility design analyses of, two industrial crawlers that included detailed design of frames, power train subsystems, and working tools; patented three lubrication sealing techniques that reduced maintenance requirements; patented a backhoe-wheel loader boom that extended its operational range; and developed manufacturing processes for flame cutting a continuous bevel and rigidly securing levers to shafts without the requirement for boring the shaft.

In 1980, Mr. Stecklein joined Southwest Research Institute as a senior research engineer. In 1984, he was promoted to section manager and promoted again in 1987 to his present position as director. In these capacities he has served as project manager on four heavy-equipment research programs for government and military sponsors; performed 35-ton haulage truck stability analysis tests; model-tested various designs of an earthmoving tool; evaluated alternate reclamation equipment systems; and researched and documented sources of airborne respirable dust as it relates to fragmentation. As manager, Mr. Stecklein was responsible for work performed in his section, including mechanical, electrical, and hydraulic design; control systems research; filtration and fine-particle technology; and failure analyses and performance evaluations as they pertain to vehicular applications.

Most recently, Mr. Stecklein has participated in the development of microcomputer-based control systems for vehicle applications including a steering system to increase vehicle maneuverability; drivetrain controllers to control engine and hydrostatic or electric drivetrain components; and vehicle cooling and hydraulic subsystems.

PROFESSIONAL CHRONOLOGY: Deere & Company, 1974-80 (design engineer, 1974-7; project engineer, 1977-80); Southwest Research Institute, 1980-(senior research engineer, 1980-4; manager, 1984-7; director, 1987-).

Memberships: Society of Automotive Engineers; American Society of Mechanical Engineers.

Patents: U.S. patent numbers 4,004,855; 4,188,146; 4,192,622; 4,203,684; 4,212,582; 4,477,987; and 4,292,002.

Rev Aug/87

Resume

Philip B. Sampson, Ph.D.
Hunt Professor of Psychology

Department of Psychology
Tufts University
Medford, Mass. 02155
Tel: (617) 381-3522

Military Service - Active duty, WWII, 1942-1946, Air Force Pilot
A.F. Reserves - retired

Education:

Sept. 1941 to Sept. 1942 - Worcester Polytechnical Institute. No Degree
Feb. 1950 to June 1952 - Tufts University, **B.S.** Psychology 1952
Sept. 1952 to Sept. 1955 - University Rochester, **Ph.D.** Psychology 1957

Employment:

1938 - 1941 temporary jobs; lumber yard, super market, truck driver.
1942 - 1946 Air Force; Military Pilot
1946 - 1948 East Coast Aviation - Chief Pilot, operations manager.
1948 - 1951 Educational Research Corporation (Harvard affil.) Pilot
1955 - present Tufts University, Prof. & former Chair, Dept. Psychology

Human Factors consulting & research activities:

Civil Aeronautics Adm. - Various studies in Aviation Psychology
Raytheon Co. - Sparrow missile, operator workstation, B 52 Bomber.
National Co. - Design of interior and workstation, communications trailer.
Laboratory for Electronics - Design of helicopter pilot display panel.
Air Force, Wright Field - cockpit visibility studies.
A.D. Little Co. - a) development of Human Factors specifications for the National Association of Aluminum Storm Door and Window Manufacturers.
b) design of operator console for loading fuel on Atlas

missile.
Sylvania Corp. - lighting studies
Dept. of Defense, R&D division - served on panel of consultants who were asked to develope recommendations concerning the training of guided missile operators and other personnel.
Office of Naval Research - determination of the dynamics of eye movements during visual tracking of moving targets.
H.E.W., Nat'l Inst of Dentistry - humans factors in the design of dental operatories.
Human Engineering Lab. , U.S. Army Aberdeen Proving Grounds - minimum space requirements for crew members in ACV.
D.O.T. Transportation System Center. Panelist on Sudden Acceleration Accidents.

Human Factors memberships:

Human Factors Society - Attended founding convention in 1957 and have been a member ever since then.
Amer. Psy Assoc. , Division 21, Engineering Psychology

Psychology memberships:

American Psychological Association - 1955 to present
Eastern Psychological Association - 1962 to present

Teaching:

At Tufts I have taught introductory, intermediate, advanced and graduate level course in Psychology, Human Factors and Engineering Psychology, from 1955 to the present. These courses were:

Introductory Psychology
Quantitative Methods
Sensory Psychology
Perception
Cognition, with lab
Introductory Engineering Psychology
Industrial Organizational Psychology
Thinking
Advanced Engineering Psychology
Advanced Projects in Human Factors
Environmental Psychology
History of Psychology
Psychometric's
Senior Seminar
Graduate Seminar in Cognition
Graduate Seminar in Human Factors

Graduate Seminar in Philosophy of Science for Psychologists
Proseminar in Psychology

I have chaired dissertation committees for about 14 Ph.D. recipients. Over half of these were in Human Factors. In this group are Deans and department Chairs of Psychology in prestigeous universities, as well as the heads of Human Factors departments in important industries.

I have also chaired thesis committees for over thirty masters Degree candidates.

A major teaching and advising responsibility is the undergraduate major in Engineering Psychology. This program was started in the mid seventies by Sampson, Mead, Hill and Kriefeldt. Mead and Hill have retired and were not replaced but the program has grown so that it is approaching 90 majors - larger than many academic departments. The program was the first undergraduate one of its type in the country, is very well received by industry, and there are still only several such programs now.

Publications:

1-6. Reports in the general area of Aviation Psychology, written on contracts with the CAA, the Air Force and the National Science Foundation.

7. Gerall, A.A., Green, R.F., Sampson P.B. and Spragg, S.D.S. Performance on a tracking task as a function of position, radius and loading of control cranks. Part I. Stationary Targets. J. of Psychology, 1956, 41, 135-143.

8. Gerall, A.A., Green, R.F., Sampson, P.B. & Spragg, S.D.S. Performance on a tracking task as a function of position, radius and loading of control cranks. Part II. Moving Targets. J of Psychology, 1956, 41, 144-156.

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Current Grants

1. Sampson, P.B. Grant procurement and administration. Biomedical Research Support Grant. Since 1977; 12 consecutive years. Current award about $79,000.

2. Sampson, P.B. , Assessment of Human Stress using Signal Detection Theory methodology. 1988-'89 award by Faculty Research Award Committee.

Recent Graduate Student Research Supervision (I have been quite involved in all this research)

1. Asiu, Bernard. Absolute judgement versus Absolute magnitude estimation to convey information through symbol magnitude changes in CRT displays. (Thesis Chair)

2. Brown, Tony. Readibility Factors Associated with Continuous Text on a CRT Display. (Thesis Chair)

3. Ziskind, David. Linear Perspective is not Linerar: Compensation for Visual Field Spansion During Movement. (Dissertation committee member-took over responsibility when Josh Bacon left)

4. O'Hearn, Brian. Spatial Mapping of Reversed Cyclopean Depth. (Thesis Chair).

5. Salvador, Tony. Positive Contrast Characters Presented on a CRT are Easier to Recognize than Negative Contrast Characters. (independent study sponsor).
Features and Emergent Features. (Thesis Chair)

6. Lesnick, Grace. Proof-reading Performance as a Function of Expectancy: The Effects of Cultural Stereotype and Experience. (Thesis Chair).

7. Russo, Patti. Organizer Elaboration and its Effect on Comprehension of Computer User Manuals. (Thesis Chair)

8. Goodman, Harold. Response Time Differences in Number Pad Use by Left vs Righthanded Individuals. (Independent Research Sponsor)

9. Weinberg, Nanci. The Physical Context of Early Behavior. (Dissertation Chair - proposal still being written)

10. Fleischman, Rebecca. Lexical Access Without Search: Evidence from Speed-Accuracy Tradeoff Paradigm. (Dissertation Committee Member - work complete).

11. Krafczek, Stacie. The Role of Syntactic Information in Visual Pattern Recognition. (Thesis committee member- work complete)

12. Hodes, Diane. Quantified Measures of Screen Layout. (Thesis committee member - work complete).

13. Geer, Shril. Orientation toward Achievement: Impact versus Process. (Thesis Chair).

14. Voland, Gerard. Using Visual/Verbal Exercises to Integrate Thought Processes and Representational Formats During Engineering Design. (Dissertation committee member).

15. Kleeman, Michael. User/CAD Interface Guidelines for Conceptual

Engineering Design. (Thesis Committee member)

16. Iyengar, Chandravalee. Development of a Multi-character Key, Text-Entry System using Computer Disambiguation: A Human Factors Approach. (Thesis committee member).

17. Coopper, Brian. Development of an Algorithm for Adaptive CAD Interface Design. (Thesis committee member).

Research in Progress

1. Interval Estimation Study. Part of a series of studies dealing with human error and randomness. About 20 more subjects need to be run.

2. Human Tracking Studies. Programming partly done. Will simulate three control orders (0,1,2) and allow for a mathematical forcing function input.

3. A Behavioral Measure of Human Stress based on Signal Detection Theory. Some programming revisions are need as well as collection of more data.

Current Committee Work

1. Departmental Committees on:
   a) The Graduate Committee
   b) Research and Equipment Committee

2. University Committes on :
   a) Faculty Research Awards Committee
   b) Committee for the Protection of Human Subjects - Acting Chair while Bushnell on sabbatical. Revised Tufts Assurance Statement (for second time) and extended our coverage to 1993.

BENJAMIN TREICHEL
Research Engineer
Vehicle Research and Development
Engine and Vehicle Research Division

B.S. in Mechanical Engineering, University of Wisconsin, 1984

Benjamin Treichel began his career as an aircraft mechanic, where he gained valuable experience in the areas of turbomachinery design and operation. This experience also provided him with a working knowledge of basic mechanical control system hardware and the production processes required to obtain very close-tolerance machined parts.

During his engineering education, Mr. Treichel worked for Argonne National Laboratory, a data acquisition and analysis facility, establishing a stirling engine test based on a HP 1000 series computer. He developed the software to control the test and obtain and analyze test data.

In 1984, Mr Treichel joined Southwest Research Institute as a Research Engineer. He developed the control systems for dual path electric and hydrostatic transmissions in military vehicles, working in the areas of flowchart preparation, software preparation, simulation and modeling, and hydraulic and electric control system component testing. He has also been involved in the data acquisition development effort associated with automatic strain data gathering instrumentation.

PROFESSIONAL CHRONOLOGY: Argonne National Laboratory, student engineer, 1982-3; Southwest Research Institute, research engineer, 1984-.

Memberships: ASME; Tau Beta Pi

Rev/Oct 86

APPENDIX B

Office Of Defects Investigation
Information Request Dated January 29, 1988

Distribution:

GM	MERCEDES
FORD	VOLVO
CHRYSLER	SAAB
NISSAN	MAZDA
TOYOTA	SUBARU
HONDA	BMW
VOLKSWAGEN	

JAN. 29, 1988

(See attached address list.)

NEF-122wjr
TSC-SA

Dear :

The National Highway Traffic Safety Administration (NHTSA) has arranged for an independent study of the "sudden acceleration" (hereafter called SA) phenomenon to be performed by several contractors, each specializing in a different area, which will be coordinated by the Transportation Systems Center (TSC) in Cambridge, Massachusetts, a government organization independent of NHTSA. This study will be performed separately from, and in addition to, normal investigative activity by the Office of Defects Investigation. Additional information is provided in the enclosed press release.

In order to perform this study, certain information which is not available from published sources such as shop manuals, etc., is required. The specific information described below is required, and additional information may be required in the near future. Pursuant to Sections 108 and 112 of the National Traffic and Motor Vehicle Safety Act (the Act), please provide the information which is described below. If you cannot provide the requested information, please state the reason.

Furnish a copy of all test reports, studies, or analyses performed by or which were performed by contractors, suppliers, or other entities for pertaining to SA in passenger cars equipped with automatic transmissions. Reports pertaining to investigations of incidents involving only specific individual vehicles need not be provided, but all reports pertaining to groups of vehicles, (e.g., specific models or model years of vehicles, specific engine designs, etc.) as well as all reports pertaining to SA in general should be provided. Relevant existing reports pertaining to human factors tests or studies, statistical studies, or groups of vehicles produced by other manufacturers should also be included.

Reports which were provided to this office in response to previous information requests need not be resubmitted provided they are referenced by investigation number (such numbers appear in the upper right hand corner of our information requests and begin with the letters PE, IR, DP, EA, or C, followed by numbers), date of correspondence, and page number. Reports dated prior to January 1, 1980, need not be provided, but may be provided at your option.

We also encourage you to provide additional comments concerning the scope or the methodology of the investigation or other recommendations relating to action NHTSA should take to obtain a better understanding of the causes of SA accidents and reduce the future incidence of such problems.

It is important that you respond to this letter on time. This letter is being sent pursuant to Section 112 of the Act, which authorizes this agency to conduct any investigation which may be necessary to enforce Title I of the Act. Your failure to respond promptly and fully to this letter may be construed as a violation of Section 108(a)(1)(B) of the Act.

Your written response, in triplicate, referencing the identification codes in the upper right hand corner of page 1 of this letter, must be submitted to this office within 15 working days from your receipt of this letter. If you find that you cannot respond within the allotted time with all the requested information, you must request an extension from the Director, Office of Defects Investigation, no later than 15 working days prior to the due date for your response. A telephone request for an extension may be made to the Director at (202) 366-2850, but it must be confirmed in writing. On-time delivery of partial submissions should be made when circumstances prevent meeting the required delivery schedule.

If any portion of your response is considered confidential information, include all such material in a separate enclosure marked confidential. In addition, you must submit a copy of all such confidential material directly to the Chief Counsel of NHTSA and comply with all other requirements of 49 CFR Part 512, Confidential Business Information.

If you have any technical questions concerning this matter, please contact Mr. Wolfgang Reinhart of my staff at (202) 366-1573.

Sincerely,

Michael B. Brownlee, Director
Office of Defects Investigation
Enforcement

Enclosure:
October 16, 1987 Press Release

APPENDIX C

Office Of Defects Investigation
Information Request Dated February 25, 1988

FEB 25 1988

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

Mr. Frank Slaveter
Technical Compliance Manager
Nissan Motor Corporation in U.S.A.
P.O. Box 191
Gardena, CA 90247

NEF-122wjr
TSC-SA

Dear Mr. Slaveter:

We informed you in a letter dated January 29, 1988, that the National Highway Traffic Safety Administration (NHTSA) has arranged for an independent study of the "sudden acceleration" phenomenon to be coordinated by the Transportation Systems Center (TSC) in Cambridge, Massachusetts, a government organization independent of NHTSA. In order to perform this study, it is necessary to obtain detailed technical design information for a selected sample of vehicles. The Nissan vehicle for which technical information is required is the 1985 Nissan 300ZX model. For purposes of this information request, the following terms are defined unless otherwise described:

- Subject vehicles: all 1985 model 300ZX Nissan vehicles equipped with standard (not turbo) engines and automatic transmissions sold in the United States.

- Nissan: all the personnel and files of the Nissan Motor Corporation in U.S.A., Incorporated, including all suppliers, contractors, and field personnel.

In order for my staff to evaluate the alleged defect, certain information is required. Pursuant to Sections 108 and 112 of the National Traffic and Motor Vehicle Safety Act (the Act), please provide numbered responses to the following items. Please repeat each item verbatim before the response. If you cannot answer any specific question, please state the reason.

1. Furnish the total number of the subject vehicles Nissan has sold in the United States. If more than one engine variation was available, provide the data broken down by engine configuration.

2. Provide a copy of all service bulletins or other written notices to dealers relating to any of the following subjects involving the subject vehicles:

   a. The braking system, or braking system components;

   b. The electrical system;

   c. The engine, including engine control systems; and

   d. Any notice relating to engine idle speed or unwanted vehicle acceleration due to any reason.

3. Provide a copy of the Part I submission to the Environmental Protection Agency describing engine control systems for the subject vehicles.

4. For the electronic control unit (or units) which control engine idle speed directly or indirectly (by controlling air flow into the engine, ignition timing, air/fuel ratio, etc.), provide the following technical information applicable to the subject vehicles with Federal (as opposed to California) emission control systems. If changes were made during production of the subject model year vehicles, provide the requested information applicable to the first group of normal production vehicles which constituted no less than 20 percent of the subject vehicles. Information pertaining to electronic cruise control units for cruise control systems should be included only if the electronic control unit is integrated in a unit which also performs other functions relating to engine idle speed.

   a. Further describe the subject vehicles which contain the above described electronic control units by providing the approximate vehicle production dates, the approximate range of Vehicle Identification Numbers, and the approximate vehicle population;

   b. Provide a brief description of the subject electronic control unit, its function, and theory of operation;

   c. Identify the vendor;

   d. Provide an electrical schematic diagram;

   e. Provide a parts lay-out drawing; and

   f. Provide the source code listings for the logic program. Provide the program translated into the English language and identify the computer language in which it is written.

5. If a cruise control system was available as standard or optional equipment (not dealer installed aftermarket systems) on any of the subject vehicles, provide the following information. If cruise control system changes were made during production of the subject model year vehicles, provide the requested information applicable to the first group of normal production vehicles which constituted no less than 20 percent of the subject vehicles.

   a. Further describe the subject vehicles which contain the above described cruise control systems by providing the approximate vehicle production dates, the approximate range of Vehicle Identification Numbers, and give the approximate vehicle population;

   b. Provide a brief description of the complete cruise control system installed in above described group of vehicles, and explain its theory of operation;

   c. Provide a brief description of the electronic control unit for the the subject cruise control system;

   d. Identify the vendor;

   e. Provide an electrical schematic diagram;

   f. Provide a parts lay-out drawing; and

   g. Provide the source code listings for the logic program. Provide the program translated into the English language and identify the computer language in which it is written.

For purposes of examination and testing, one functional sample electronic control unit, as described in Item Number 4, and a cruise control system control unit, as described in Item Number 5, are required. Since the testing may ultimately be destructive, such units would not be returned. Your assistance in voluntarily providing such units would be greatly appreciated. If you are able to provide such units please send them as soon as practical to this office. If you are not able to provide such units, please provide suggestions how we could obtain them.

It is important that Nissan respond to this letter on time. This letter is being sent pursuant to Section 112 of the Act, which authorizes this agency to conduct any investigation which may be necessary to enforce Title I of the Act. Your failure to respond promptly and fully to this letter may be construed as a violation of Section 108(a)(1)(B) of the Act.

Your written response, in triplicate, referencing the identification codes in the upper right hand corner of page 1 of this letter, must be submitted to this office within 20 working days from your receipt of this letter. If you find that you cannot respond within the allotted time, with all the requested information, you must request an extension from the Director, Office of Defects Investigation, no later than 5 working days prior to the due date. A telephone request for an extension may be made to the Director at (202) 366-2850, but it must be confirmed in writing.

If any portion of your response is considered confidential information, include all such material in a separate enclosure marked confidential. In addition, you must submit a copy of all such confidential material directly to the Chief Counsel of NHTSA and comply with all other requirements of 49 CFR Part 512, Confidential Business Information.

If you have any technical questions concerning this matter, please contact Mr. Wolfgang Reinhart of my staff at (202) 366-1573.

Sincerely,

Original signed by
Michael B. Brownlee

Michael B. Brownlee, Director
Office of Defects Investigation
Enforcement

cc:
Mr. Tomoyo Hayashi
Engineering Staff, Safety
Nissan Research & Developement, Inc.
1919 Pennsylvania Ave, NW, Suite 707
Washington, DC 20006

APPENDIX D

Technical References

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