U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

DOT-HS-807-367
DOT-TSC-NHTSA-89-1
Final Report

January, 1989

An Examination of Sudden Acceleration

John Pollard
E. Donald Sussman

U.S. Department of Transportation
Research and Special Programs
Administration
Transportation Systems Center
Cambridge, MA 02142

Prepared for

**National Highway Traffic Safety Administration
Office of Defects Investigation
400 7th Street, SW
Washington, DC 20590**

Technical Report Documentation Page

1. Report No.
DOT-HS-807-367

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
An Examination of Sudden Acceleration

5. Report Date
January 1989

6. Performing Organization Code
DTS-45

7. Author(s)
John Pollard and E. Donald Sussman

8. Performing Organization Report No.
DOT-TSC-NHTSA-89-1

9. Performing Organization Name and Address
U.S. Department of Transportation
Research and Special Projects Administration
Transportation Systems Center
Cambridge, MA 02142

10. Work Unit No. (TRAIS)
HS910/S9024

11. Contract or Grant No.
N.A.

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
National Highway Traffic Safety Administration
400 7th Street, S.W.
Washington, DC 20590

13. Type of Report and Period Covered
Final Report
1987 - 1988

14. Sponsoring Agency Code
NEF-10

15. Supplementary Notes

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.

17. Key Words
Sudden Acceleration, Vehicles, Pedal Design, Engine Controls, Cruise Control, Brakes, Human Factors

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE PUBLIC
THROUGH THE NATIONAL TECHNICAL
INFORMATION SERVICE, SPRINGFIELD,
VIRGINIA 22161

19. Security Classif. (of this report)

20. Security Classif. (of this page)

21. No. of Pages

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

Notice

Notice

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.

TABLE OF CONTENTS

Executive Summary

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 :

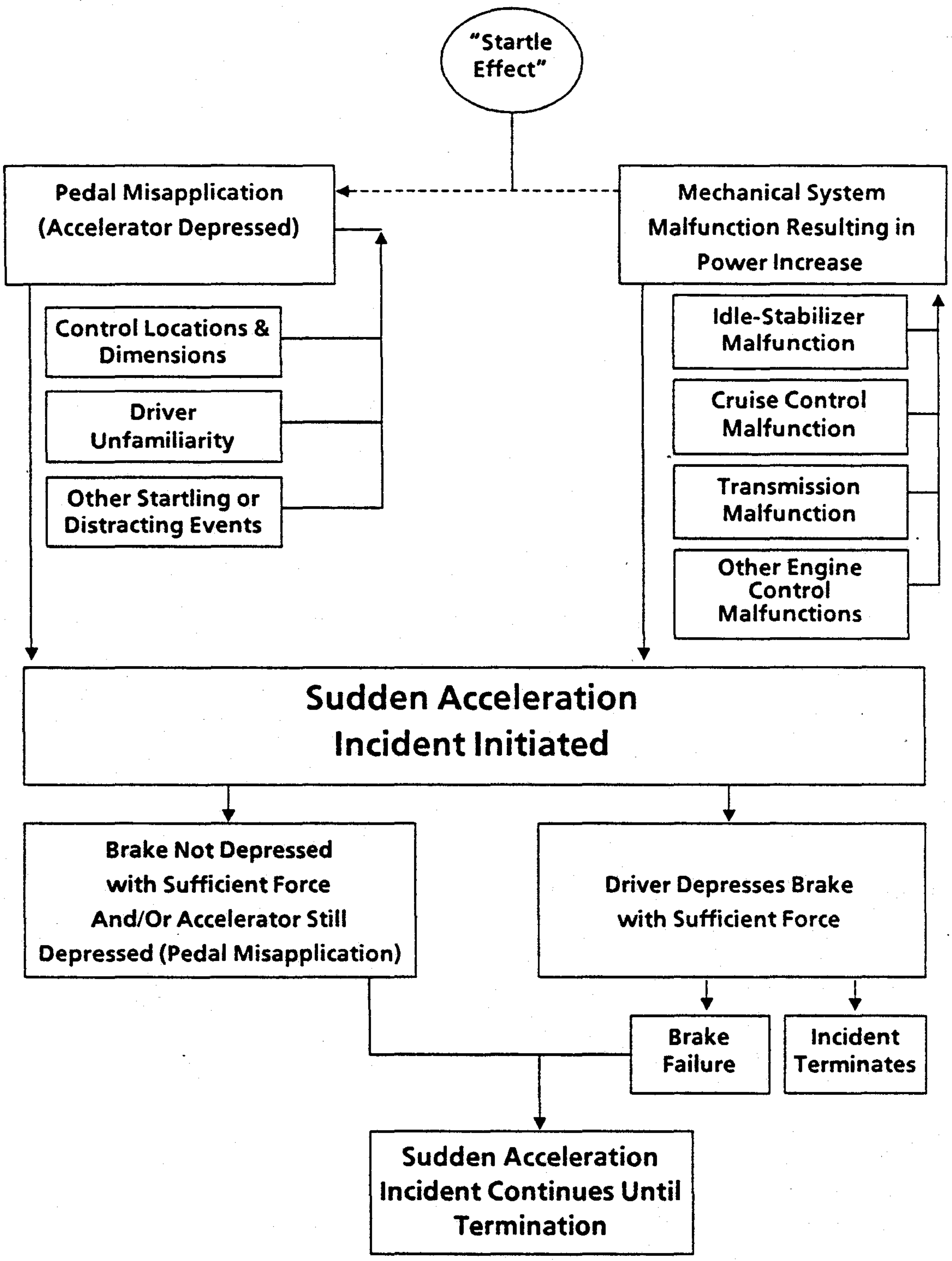
- engines and their controls, as well as transmissions, to determine whether and how they might produce unwanted power;

- 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.

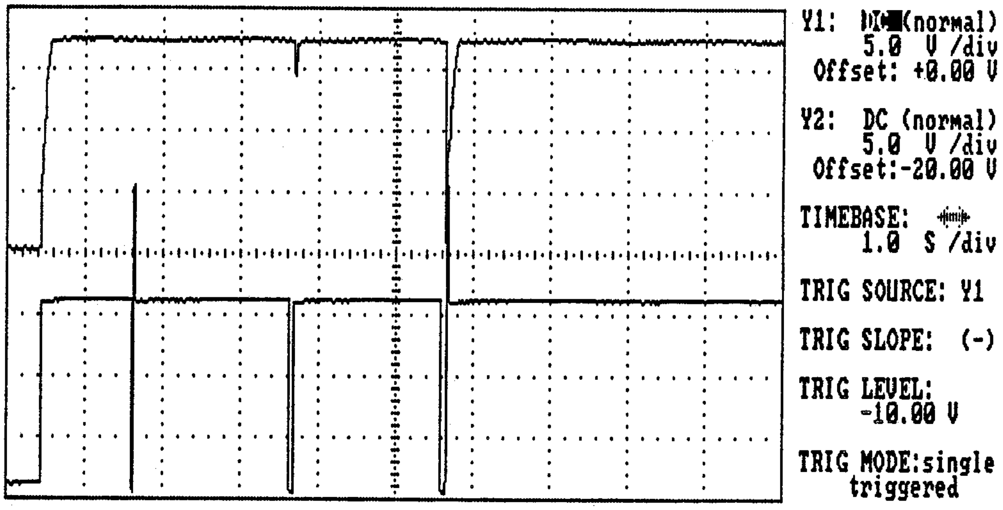
Except for one unit which would not function at all due to a misadjusted brake-pedal switch, no anomalies were found in any of these units.

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.

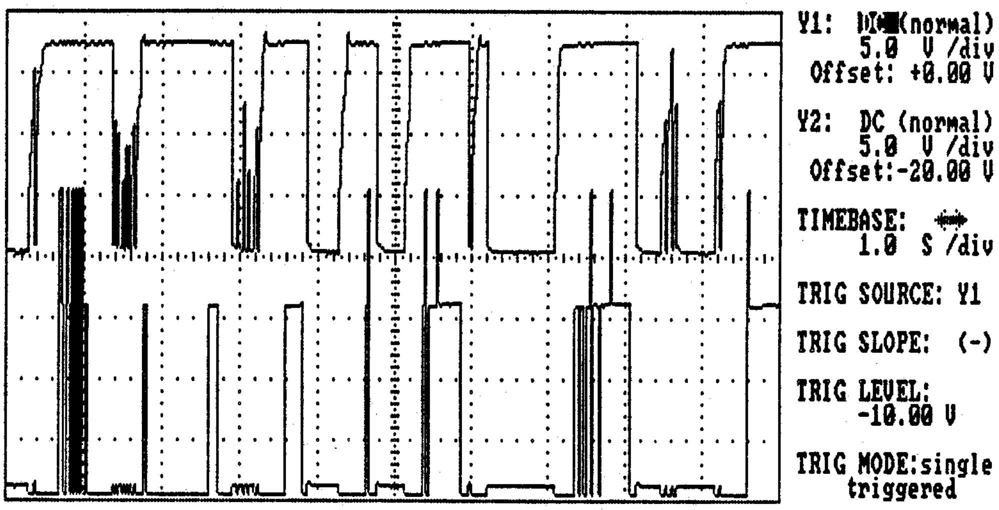
For all of the reasons described above and because the RSAI rates are not significantly different for cruise-control-equipped vehicles versus those without them, cruise controls are not an important factor in SAI problems.

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.



```
Y1:  DC (normal)
         5.0  V /div
  Offset: +0.00 V

Y2:  DC (normal)
         5.0  V /div
  Offset:-20.00 V

TIMEBASE:
         1.0  S /div

TRIG SOURCE: Y1

TRIG SLOPE:  (-)

TRIG LEVEL:
        -10.00 V

TRIG MODE:single
     triggered
```

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%.



```
Y1:  DC (normal)
         5.0  V /div
  Offset: +0.00 V

Y2:  DC (normal)
         5.0  V /div
  Offset:-20.00 V

TIMEBASE:
         1.0  S /div

TRIG SOURCE: Y1

TRIG SLOPE:  (-)

TRIG LEVEL:
        -10.00 V

TRIG MODE:single
     triggered
```

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.

Vehicle	Throttle Open While Braking			Throttle Closed While Braking		
	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.

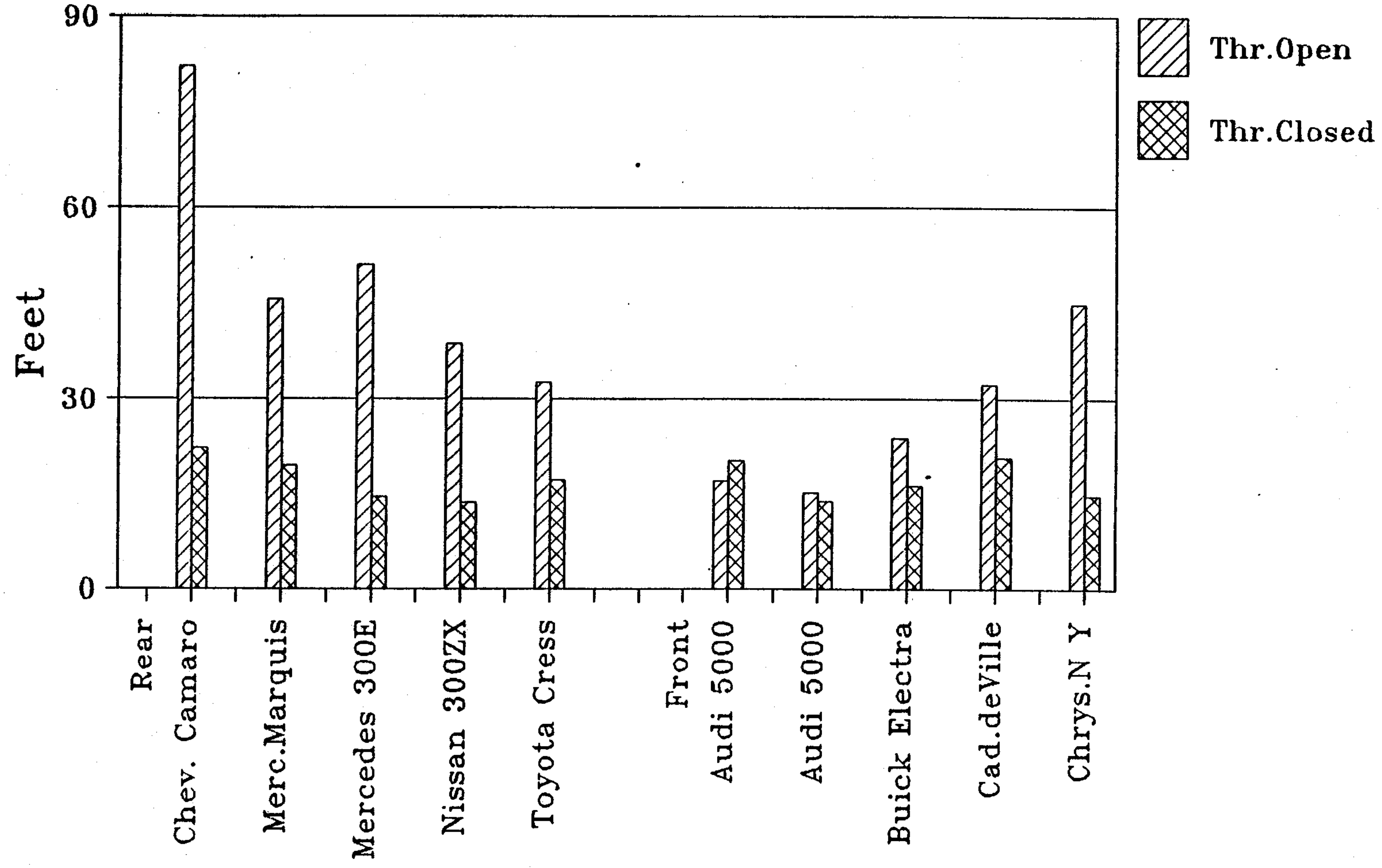


Table 3.1.5-3 shows the results of braking tests from an initial speed of 30 mph in reverse. Brakes were applied with a force sufficient to produce minimum stopping distance (this force was determined experimentally). Under one test condition the throttle was held open until the vehicle came to a stop. 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 next to car with tx	Dry ground	3.91	E	13	161	161	81	76	51	Ant on left rear fender
	Dry ground	7.28	E	8	116	116	116	92	58	Ant on left rear fender
	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 next to Car with tx	Dry ground	40.27	E	21	95	95	82	58	34	Ant center of roof 110 w
	Dry ground	40.27	E	21	67	58	50	26	21	Ant center of roof 110 w
	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 next to Tractor-trailer with tx	Dry ground	40.27	E	20	171	116	95	48	21	Ant center of roof 110 w
	Dry ground	162.475	E	20	58	37	34	26	12	Ant center of roof 110 w
	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	101.5 180 204 60	E	25*	26	21	21	18	15	182 m (200 yd) 18 m (60 ft) 18 m (60 ft) 91 m (100 yd)	KHEP-FM tx, 100 kW KAET-TV, tx, Channel 8, 117 KW vis 16.2 kW aur KTAR-TV, Channel 12, 316 kW vis, 46.8 kW aur 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.

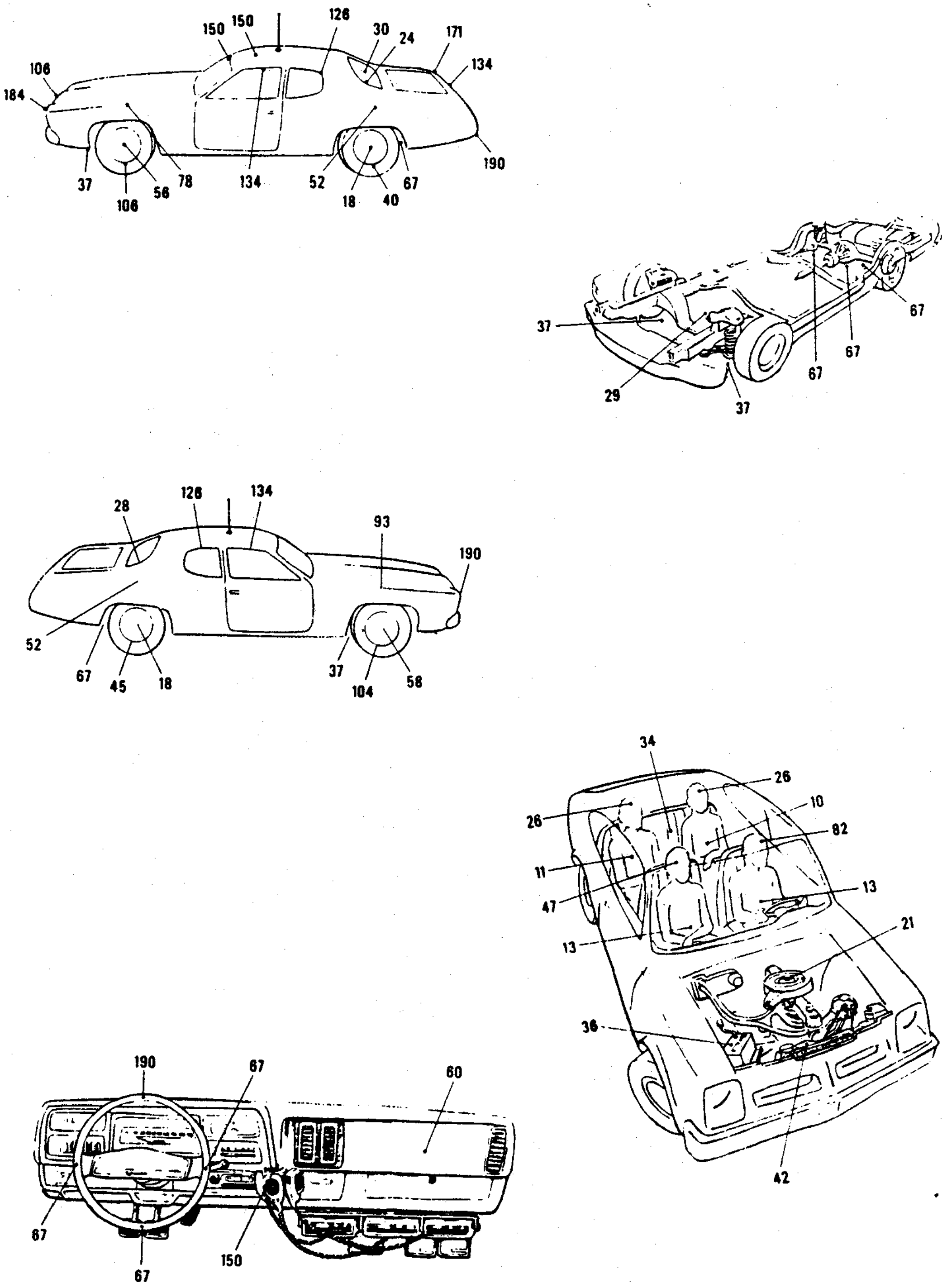


Figure 3.2.2-2: E field measurements, normalized 50th percentile values plotted against frequency. Maxima occur in the AM broadcast and CB (illegal) tests. Source: Reference 36.

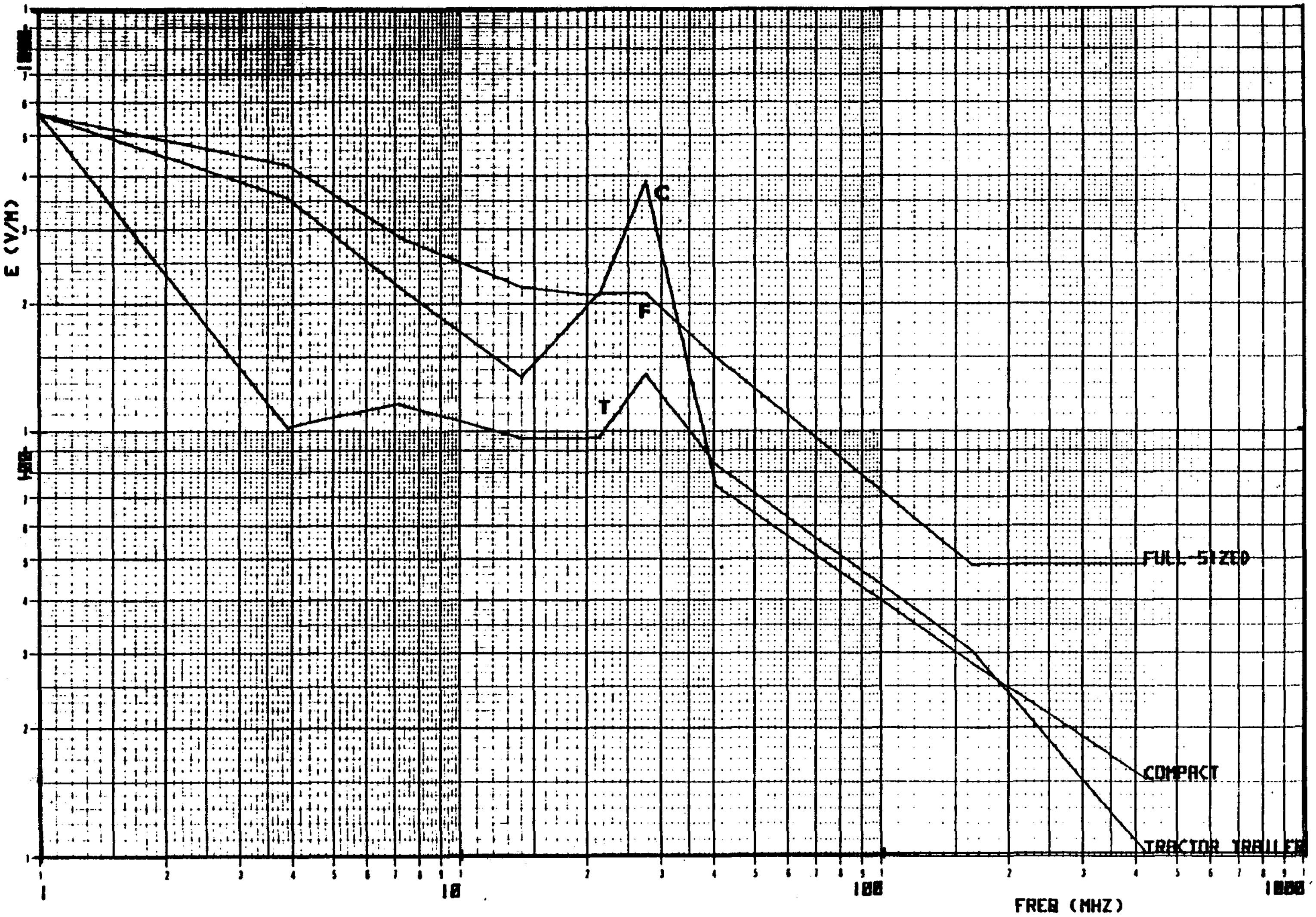


FIG. 39 - E FIELD, WORST CASE, NORMALIZED, 50 PERCENTILE

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.

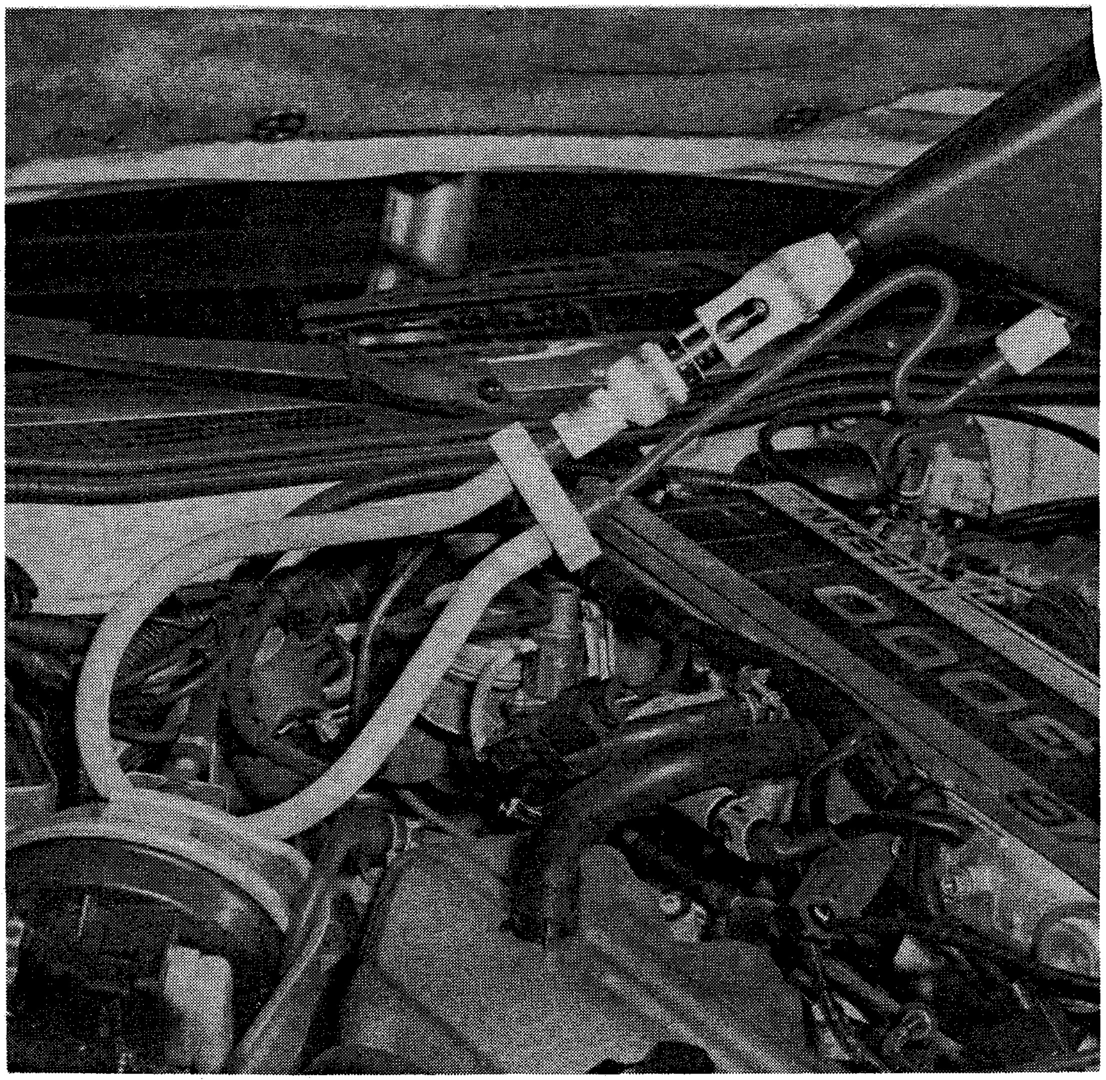
During the course of tests at VRTC, each of the vehicles was exposed to several hundred spark discharges at various points in its engine compartment and under its dashboard. The discharges were concentrated in the vicinity of the cruise control, its actuator and its wiring harness. Hundreds of magnetic 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.

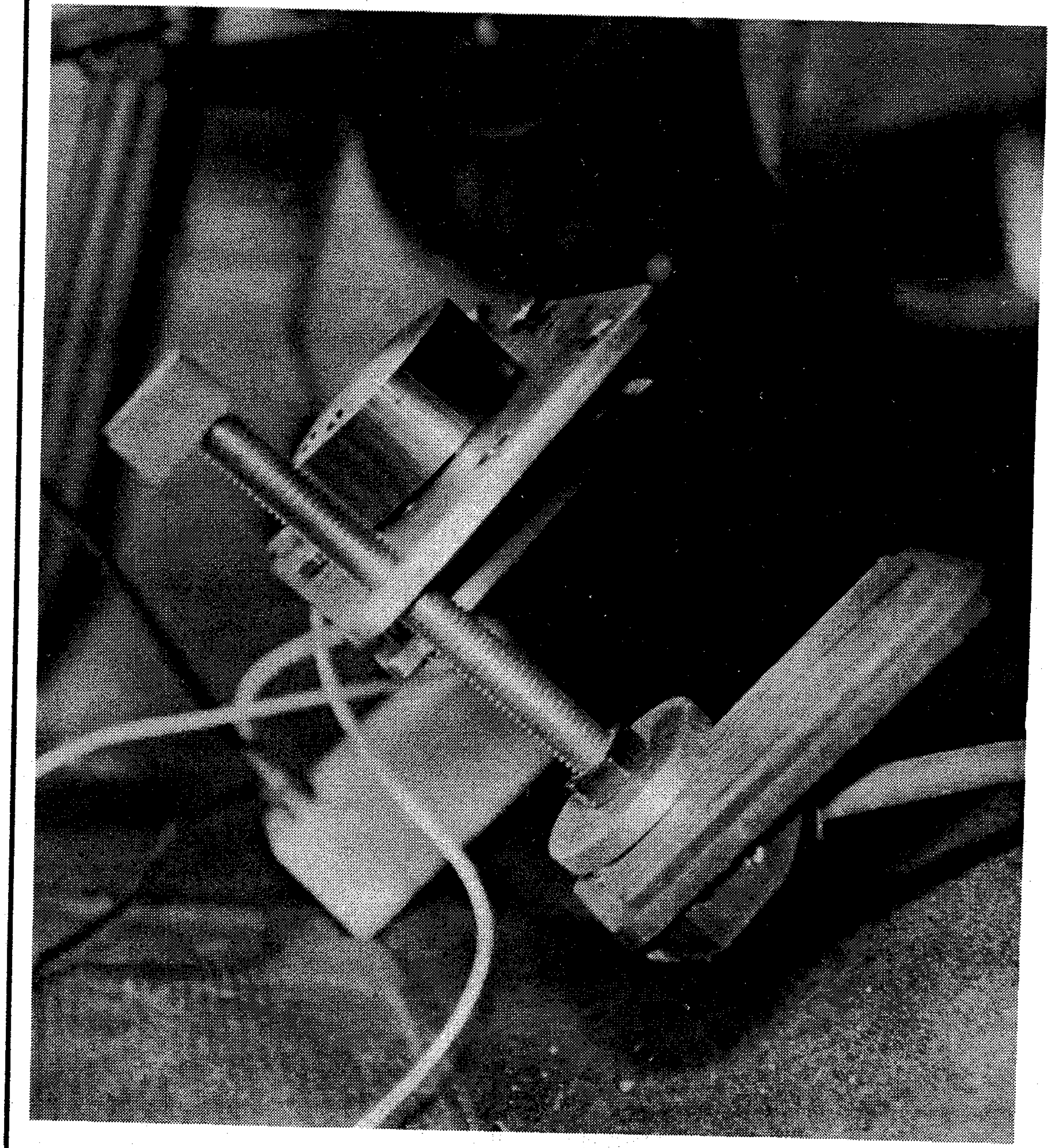
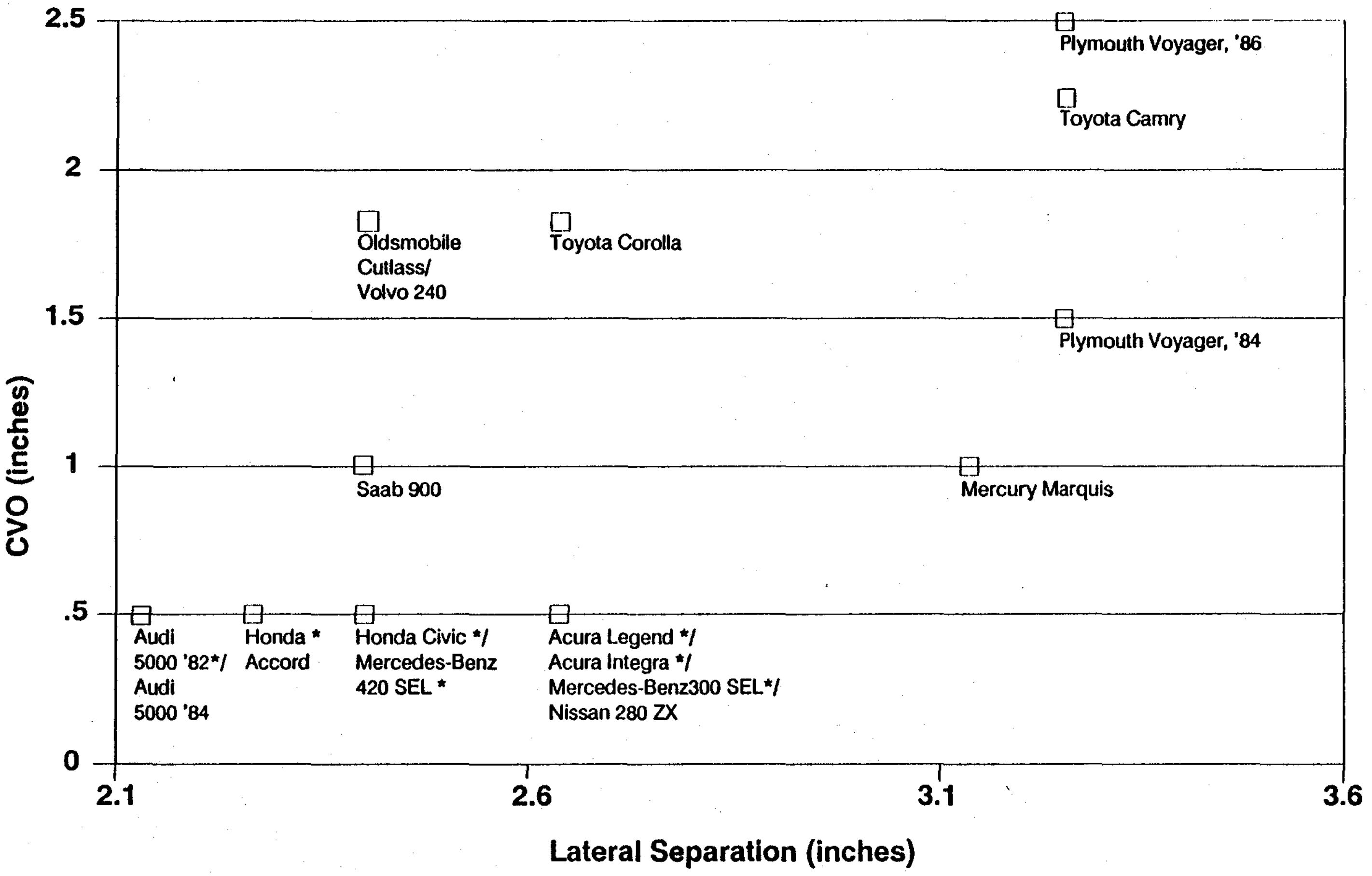


Figure 3.3.1-2: Scatter plot of pedal separation measures for various vehicles. All of the vehicles with vertical offset measurements of less than one inch have above-average rates of RSAI except the Honda Civic. The Mercury Marquis does have an above-average rate, which is not true of the other vehicles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



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

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.

Source: TSC

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.

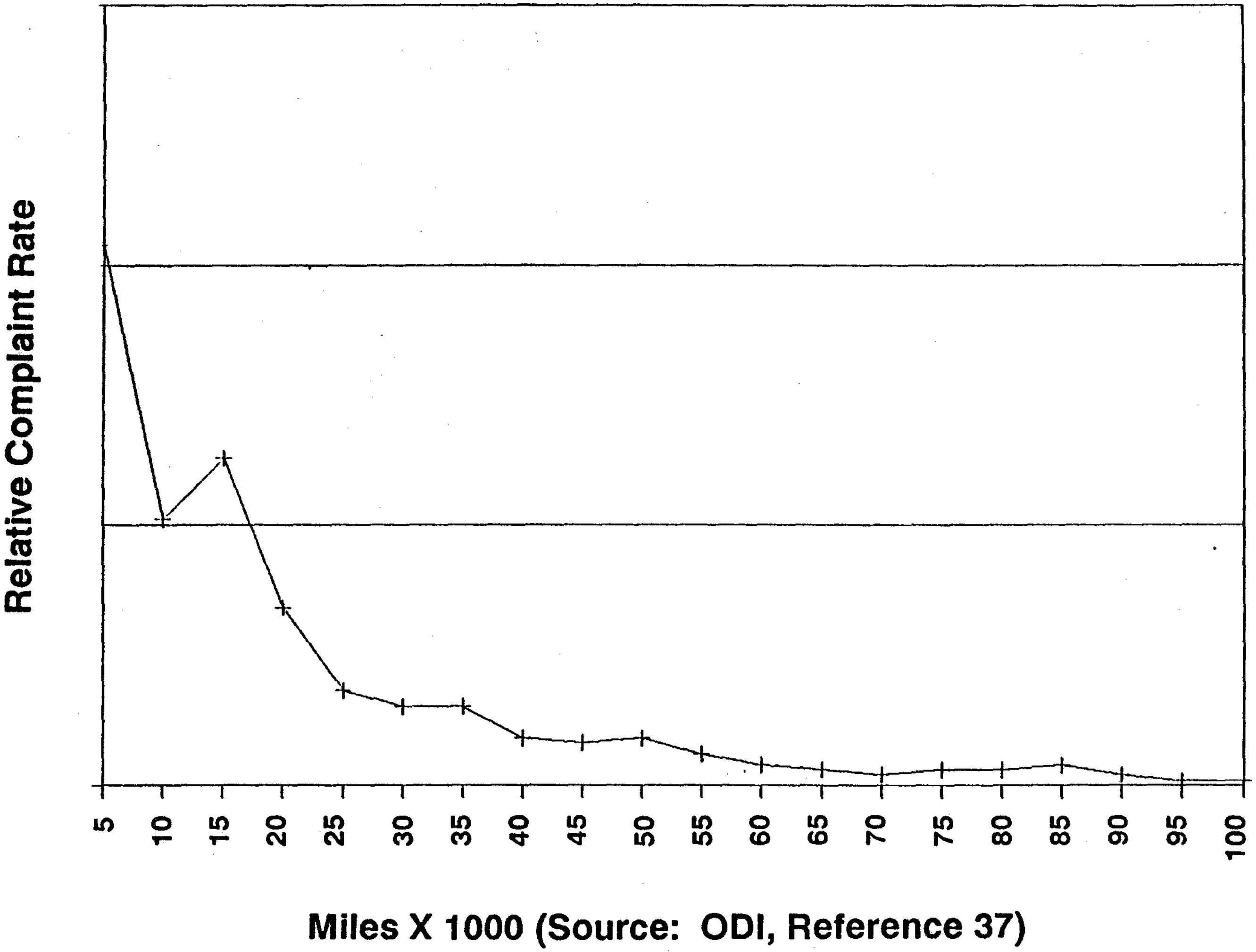
The exception to this is driver familiarity with the vehicle, which can usually be estimated from the odometer readings found in the complaint data. Review of the data recently gathered by NHTSA reveals that the rate of complaints about unwanted engine power falls off precipitously with vehicle milage, 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.



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.

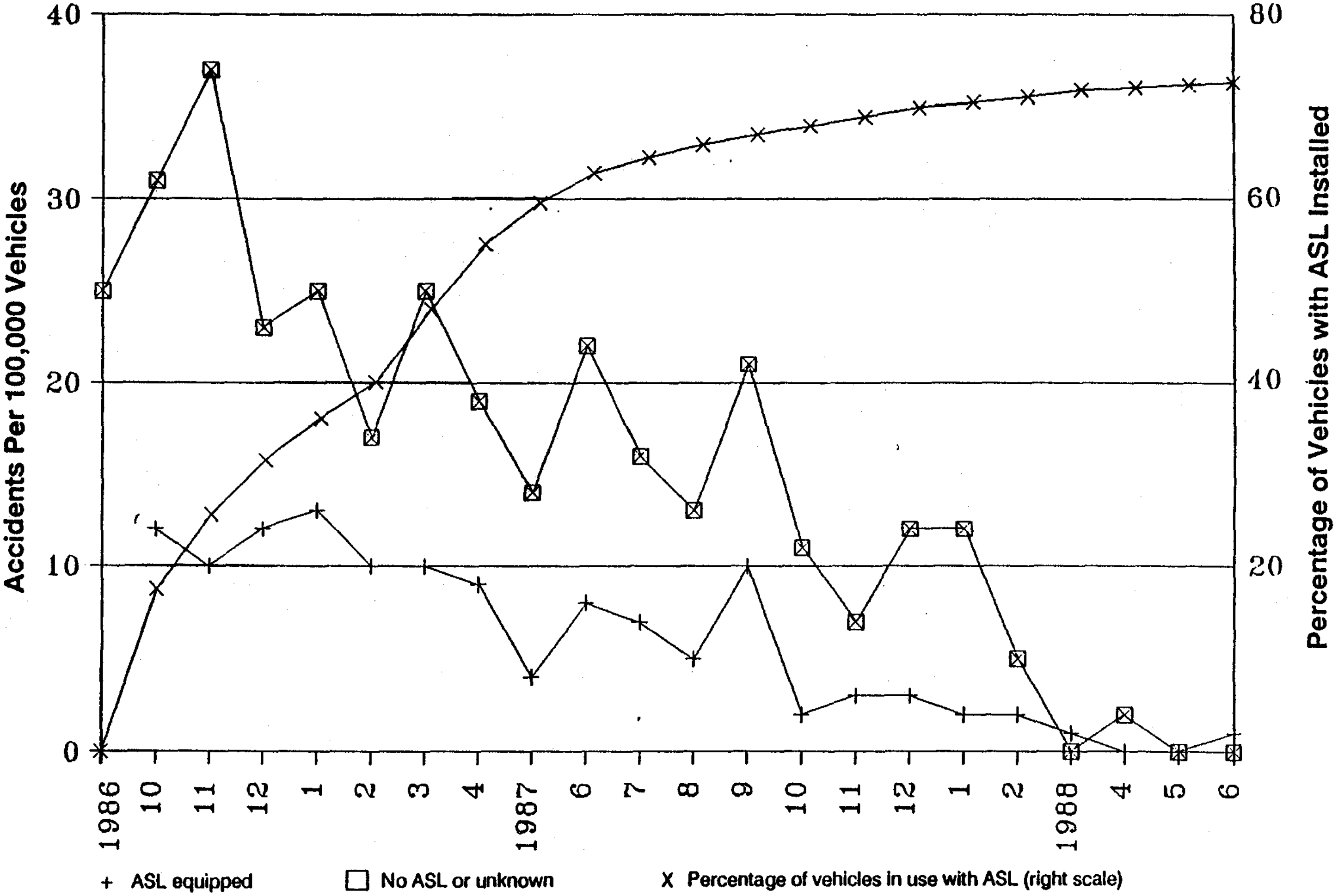
3.3.2 AUTOMATIC-SHIFT-LOCK EFFECTS

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.

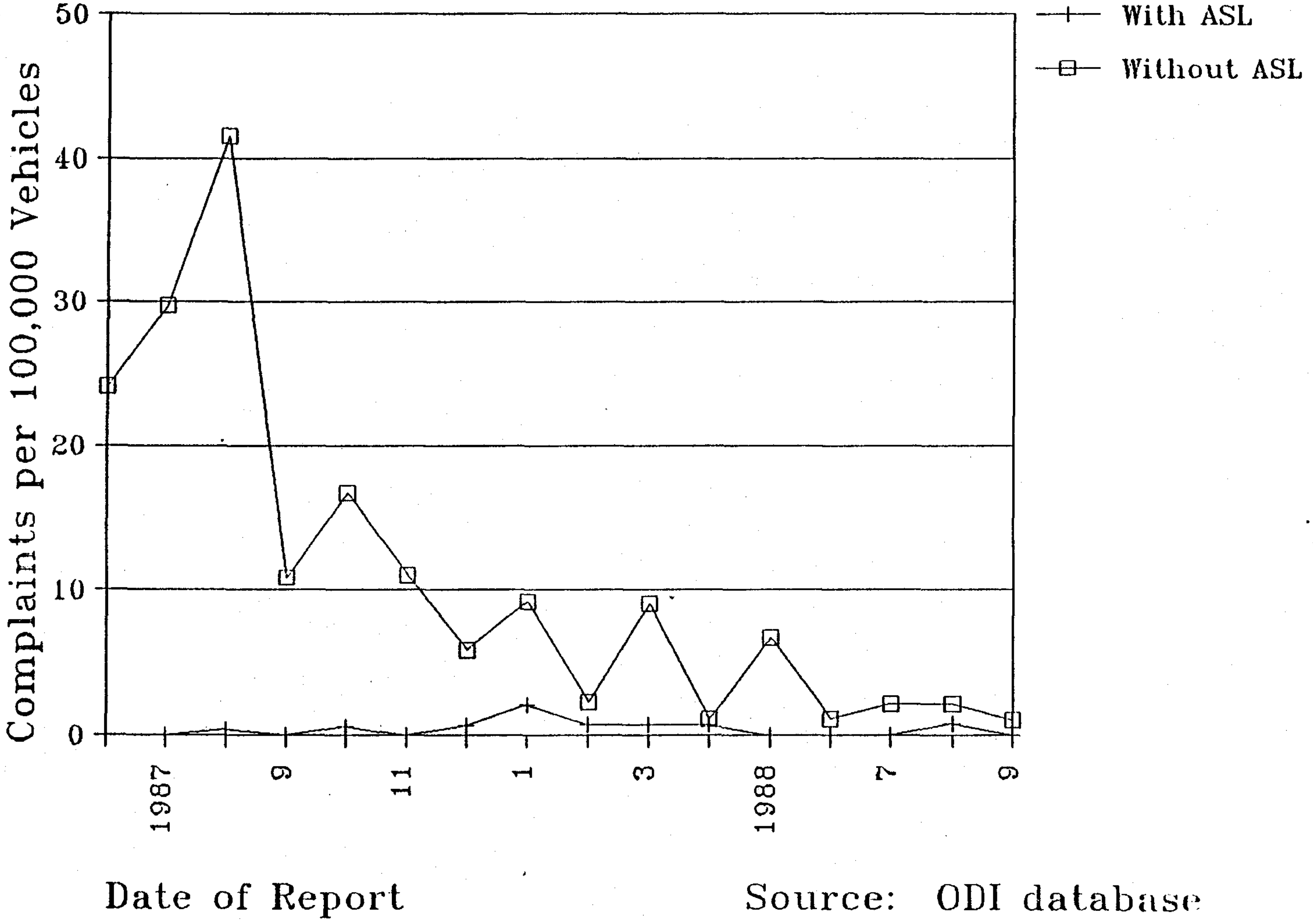
Figure 3.3.2-1: Comparison of RSAI for Audi 5000 cars with and without the ASL installed.



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.



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

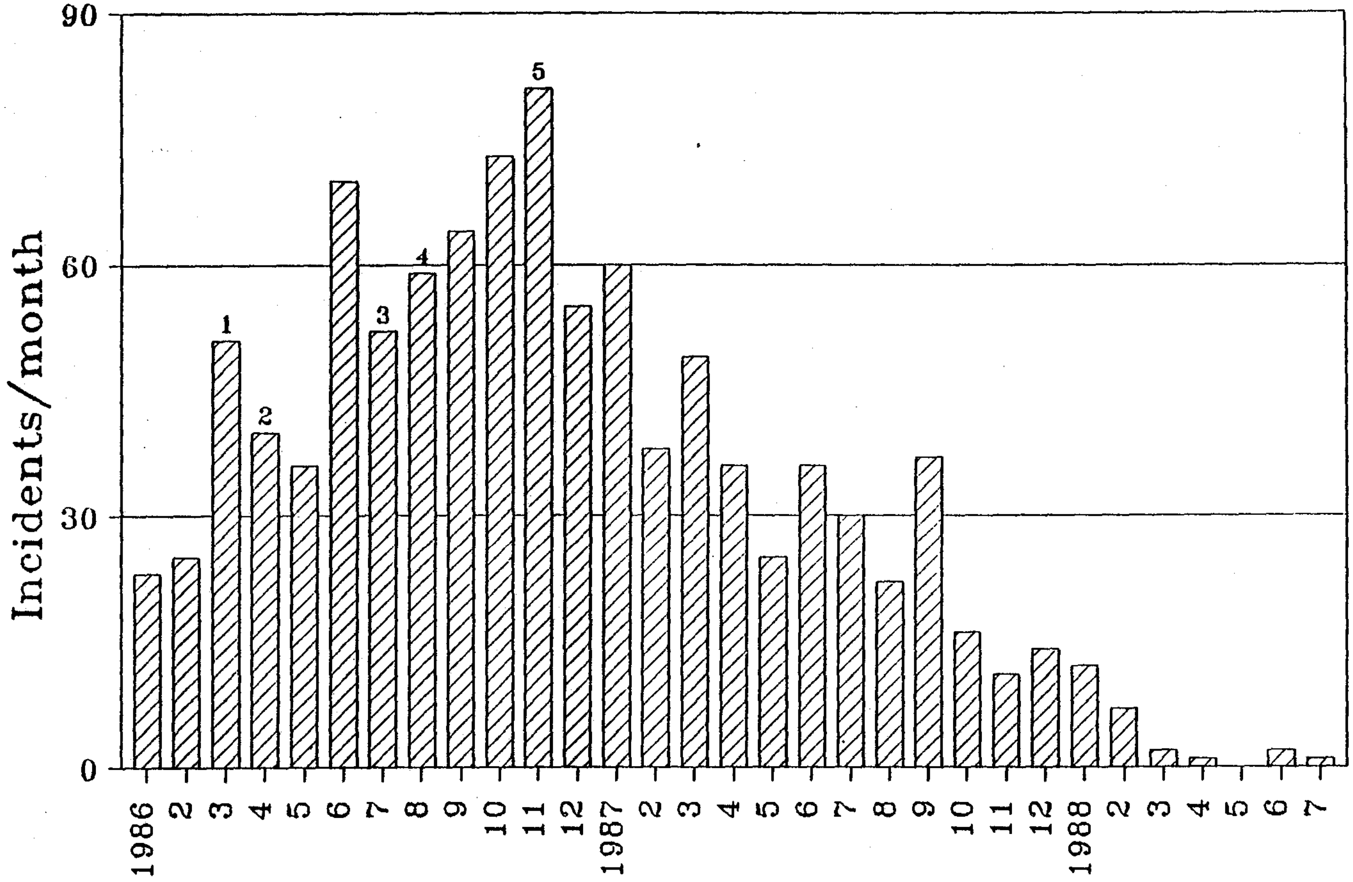
Some bias in the comparative RSAI rates among vehicle makes could result from differences in the socioeconomic status of owners or drivers. Wealthier, better-educated drivers may have a higher propensity to make their sudden-acceleration accidents known to the government and the media, which could lead 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.

Massachusetts Institute of Technology
Bldg. 3-340
Cambridge, MA 02136
(617) 253-2243

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-.

Rev/Nov 87

RAYMOND MAGLIOZZI

Owner & Operator
Good News Garage
75 Hamilton Street
Cambridge, Massachusetts 02139
(617) 354-5383

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.

9. Gerall, A.A., Sampson P.B., & Spragg S.D.S. Method for studying performance on a simple tracking task as a function of radius and loading of control cranks. Army Medical Research Lab. Proj. #6-95-20-001. Rpt#144, April 1954.

10. Gerall, A.A., Sampson P.B. & Boslov, G.L. Classical conditioning of the human pupillary dilation. J. of Exp. Psychol. , 1958, 54, 467-474.

11. Sampson, P.B. The effect of physical characteristics of controls on the intermittency of human tracking performance. University of Rochester, Rochester, N.Y., 1957. (Ph.D. Dissertation).

12. Wulfeck, J. et. al. Vision in Military Aviation. W.A.D.C. Tech. Rept. 58-399, 1958. (Three chapters in this document were written by me.)

13. Sampson, P.B., Devoe, D. Human Factors in Helicopter

Instrumentation. A survey of the literature / A report of interviews with helicopter pilots. Contract AF33(600) 34034. Laboratory for Electronics, Boston, Mass. 1957.

14. Ronco, P.G. , Chandlee, J. & Sampson, P.B. Human Factors in Helicopter Instrumentation: An evaluation of two navigation displays. Contract AF33(600) 34034. Laboratory for Electronics, Inc., Boston, Mass. 1958.

15. Sampson, P.B. Human Factors in Helicopter Instrumentation: Hovering Displays. Contract AF33(600) 34034. Laboratory for Electronics, Inc Boston, Mass. 1958.

16. Sampson, P.B. Human Factors in Helicopter Instrumentation: A final report. Contract AF33(600) 3404. Subcontract #484-76004, Laboratory for Electronics, Inc., Boston, Mass. July 1959.

17. Sampson, P.B. Experimenting with people, a review of a book by Chapanis, A. Research Techniques in Human Engineering. Published in Contemporary Psychology. Sept. 1959.

!8. Sampson, P.B. & Coleman, P. The feasibility of using the eye as a source of control signals in tracking. Physiological Psychology Branch, Office of Naval Research, Contract Nonr 494-(16) Proj. #N.R. 144-122, Washington, D.C. 1959.

19. Sampson, P.B. Head and eye tracking in response to velocity and acceleration inputs. Physiological Psychology Branch, Office of Naval Research. Contract Nonr 494(16) Proj. #N.R. 144-122, Washington, D.C. April 1960.

19a. The preceding monograph included in:
Levey-Schoen, Ariane. L'Etude Des Mouvements Oculaires; Revue des techniques et des connaissances. Ouvrage publie avec le concours du centre National de la recherche scientifique. Dunod, Paris. 1969.

20. Elkin, E.H. & Sampson, P.B. Head and eye tracking movements in response to velocity and acceleratation inputs. XIV International Congress of Applied Psychology. Copenhagen, Denmark 1961.

21. Sampson, P.B. & Wade, E.A. Literature survey on Human Factors in visual displays. RADC TR61-95, Contract AF30(602)2358. Rome Air Developement Center, N.Y., June 1961.

22. Sampson, P.B. & Elkin, E.H. Levels of display integration in compensatory tracking. J. Perceptual Motor Skills, 1965, 20 , 59-62.

23. Sampson, P.B. Use of A-D converters in computer automated research. (In-house technical document). Decision Sciences Laboratory. Air

Force, Electronics Systems Division, Hanscomb Field. 1965

24. Hill, P. and Sampson, P.B. Biodental Research Methodology. Biodental Monograph Series. H.E.W. National Institute of Dentistry. 1969.

25. Sampson, P.B., and Hill, P. A Survey of Dental Practice. Biodental Monograph Series. H.E.W. National Institute of Dentistry. 1970.

26. Mead, P.G. and Sampson P.B. Hand steadiness during unrestricted linear arm movements. Human Factors 1972 14(1). p. 45-50.

27. Sampson, P.B. and Ashkouri, H. Minimal Space Requirements for Humans in ACVs. (Final Report) Aberdeen Proving Ground, Maryland. April 1982.

28. Pollard, J. ed. Interim report of panel on sudden acceleration. Transportation Systems Center. Cambridge Mass. Oct. 1988. (Sampson,P.B. panel member and contributer)

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 Paragigm. (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
FORD
CHRYSLER
NISSAN
TOYOTA
HONDA
VOLKSWAGEN
MERCEDES
VOLVO
SAAB
MAZDA
SUBARU
BMW

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~~d~~ 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:

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

1. Audi of America. *Audi 5000, 5000S Official Factory Repair Manual: 1977, 1978, 1979, 1980, 1981, 1982, 1983.* Cambridge, MA: Robert Bentley, Inc., 1986.

2. Audi of America. *Audi 5000S Official Factory Repair Manual: 1984, 1985*. Cambridge, MA: Robert Bentley, Inc., 1985.

3. Bearden, William O. "Profiling Consumers Who Register Complaints Against Repair Services," *Journal of Consumer Affairs,* Vol. 17, pp. 315-355, 1983.

4. Bearden, William O., and Teel, Jesse E. "Selected Determinants of Consumer Satisfaction and Complaint Reports," *Journal of Marketing Research.* Vol. 20, pp. 21-28, 1983.

5. Bosch, Robert. *Automotive Electric/Electronic Systems*. Stuttgart: Robert Bosch GmbH, 1988 (available as SAE publication # ISBN 0-89-883-509-7)

6. Bosch, Robert. *Automotive Handbook*. Stuttgart: Robert Bosch GmbH, 1988 (available as SAE publication # ISBN 0-89-883-518-6)

7. Chrysler Corporation. *1984 Electrical and Engine Service Manual for Front Wheel Drive Passenger Vehicles.* Detroit, MI: Chrysler Corp., 1983.

8. Csere, Csaba. "Audi Agonistes." *Car & Driver*, June, 1987, pp. 51-57.

9. Daimler-Benz AG. *Model Year 1986, USA, Mercedes-Benz Service*. Stuttgart: Daimler-Benz AG,1985.

10. *Detroit News*. Five-part series of articles on all aspects of sudden acceleration, December 13-17, 1987.

11. Dreyfus Associates, Henry. *Humanscale 1/2/3.* Cambridge, MA: The MIT Press, 1981.

12. Ford Motor Company. *1984 Car Shop Manuals: Body, Chassis, Electrical, Powertrain, & Engine/Emissions Diagnosis*. Detroit, MI: Ford Motor Company, 1983.

13. General Motors, Inc., A.C. Spark Plug Division. Internal Memorandum dated November 26, 1984 from M. Sark to D. Crawford et al describing analysis of failures of a batch of eighteen cruise controls exhibiting a no-vent condition. (memorandum included in General Motors' response to NHTSA letter reproduced in Appendix B)

14. General Motors, Inc. Buick Motor Division. *1986 Buick Shop Manual*. Detroit, MI: General Motors, 1986.

15. General Motors, Inc. Cadillac Motor Car Division. *1985 Cadillac Service Information Final Edition*. Detroit, MI: General Motors, 1985.

16. General Motors, Inc. Chevrolet Motor Division. *1984 Camaro Shop Manual*. Detroit, MI: General Motors, 1984.

17. General Motors, Inc. GM Technical Center. *Automotive Human Factors Report #87-1003: Unwanted Acceleration Study*. Prepared by Beth A. Rosa. Warren, MI: General Motors, 1987.

18. Gilly, Mary C. "Consumer Complaint Behavior." Unpublished research paper. Graduate School of Management, University of California, Irvine, 1988.

19. Institution of Mechanical Engineers. *Fifth International Conference on Automotive Electronics*. London: Mechanical Engineering Publications, Ltd., 1985. (available through the SAE as MEP-230)

20. Kraft, Frederic. "Characteristics of Consumer Complainers and Complaint and Repatronage Behavior." *Consumer Satisfaction, Dissatisfaction and Complaining Behavior.* Edited by Ralph L. Day. Bloomington, IN: Bureau of Business Research, Indiana University, 1977.

21. Lankard, Tom. "Unintended Acceleration." *Autoweek*, January 19, 1987, pp. 23-34.

22. Mercedes-Benz of North America, Inc. *Electrical Troubleshooting Manual Models 124 and 201, Starting Model Year 1984.* Montvale, NJ: Mercedes-Benz of North America, 1987.

23. Mercedes-Benz of North America, Inc. Video tape and notes documenting the "ACCELERATION TEST PROGRAM" conducted November 25, 1986, on a 1986 Mercedes-Benz 300E. Montvale, NJ: Mercedes-Benz of North America, 1987.

24. Nissan Motor Company. *Nissan 300ZX 1985 Service Manual*. Tokyo: Nissan Motor Company, 1984.

25. Nitta, Shuichi. "Demonstration of ESD Testing" included in *Close Up*, broadcast by NHK television on June 30, 1987.

26. Rogers, S.B. & Wierwille, W.W. "The Occurrence of Accelerator and Brake Pedal Actuation Errors during Simulated Driving." *Human Factors*, 1988, 30(1), pp. 71-81.

27. Society of Automotive Engineers. *Automotive Electronics*. (SP-388) Warrendale, PA: Society of Automotive Engineers, 1973.

28. Society of Automotive Engineers. *Automotive Electronic Engine Management and Driveline Controls*. (SP-705) Warrendale, PA: Society of Automotive Engineers, 1987.

29. Society of Automotive Engineers. *Automotive Electronics Reliability*. (SP-696) Warrendale, PA: Society of Automotive Engineers, 1987.

30. Society of Automotive Engineers. *Automotive Electronics Reliability Handbook*. (AE-9) Warrendale, PA: Society of Automotive Engineers, 1987.

31. Society of Automotive Engineers. *Engine and Driveline Control Systems.* (SP-739) Warrendale, PA: Society of Automotive Engineers, 1988.

32. Swedish Defense Research Establishment. Department of Information Technology. *Risk Assessment of Cruise Control*, by Mats Gunnerhed. Linkoping, Sweden: SDRE/FOA, 1988 (available through the Swedish Embassy, Washington, D.C.)

33. Tomerlin, John. "The Riddle of Sudden Acceleration." *Road & Track*, February, 1988, pp.52-59.

34. Tomerlin, John. "Pedal Errors in Several Make and Model Cars." Unpublished paper. August, 1988.

35. Toyota Motor Corporation. *Toyota Cressida 1984 Repair Manual.* Tokyo: Toyota Motor Corp., 1984.

36. U.S. Department of Commerce. National Bureau of Standards. *Electromagnetic Interference (EMI) Radiative Measurements for Automotive Applications*, by John Adams et al, NBS Technical Note 1014, Washington, D.C.: Government Printing Office, 1979.

37. U.S. Department of Transportation. National Highway Traffic Safety Administration, Office of Defects Investigation.

38. U.S. Department of Transportation. National Highway Traffic Safety Administration, Vehicle Research and Test Center. *Control Pedal Performance Evaluation — Foreign Vehicles*, by Peter Sursi and Harry Mullins. East Liberty, OH: VRTC, 1984.

39. U.S. Department of Transportation. National Highway Traffic Safety Administration, Vehicle Research and Test Center. *Driver Reaction to Unexpected Fast Engine Speed and Sudden Unwanted Acceleration*, by Daniel Pearse. East Liberty, OH: VRTC, 1988.

40. U.S. Department of Transportation. National Highway Traffic Safety Administration, Vehicle Research and Test Center. Performance Documentation of a 1982 Audi 5000S in Relation to Surprise Acceleration, by Daniel Pearse. East Liberty, OH: VRTC, 1987.

41. U.S. Department of Transportation. National Highway Traffic Safety Administration, Vehicle Research and Test Center. *Performance Documentation of a 1985 Audi 5000S in Relation to Surprise Acceleration*, by Daniel Pearse. East Liberty, OH: VRTC, 1987.

42. U.S. Department of Transportation. National Highway Traffic Safety Administration, Vehicle Research and Test Center. *Determination of a 1984 Audi 5000S Susceptibility of Idle Electronic Control Unit to Damage in Relation to Surprise Acceleration*, by Daniel Pearse. East Liberty, OH: VRTC, 1988.

43. U.S. Department of Transportation. National Highway Traffic Safety Administration, Vehicle Research and Test Center. *Inspection and Testing of a 1984 Audi 5000S for Surprise Acceleration*, by Daniel Pearse. East Liberty, OH: VRTC, 1987.

44. U.S. Department of Transportation. National Highway Traffic Safety Administration, Vehicle Research and Test Center. *Inspection and Testing of a 1985 Audi 5000S for Surprise Acceleration*, by Daniel Pearse. East Liberty, OH: VRTC, 1987.

45. U.S. Department of Transportation. Transportation Systems Center. *Analysis of Data Related to Sudden Vehicle Acceleration Accidents*. Unpublished Technical Memorandum containing proprietary information. Cambridge, MA: TSC, 1985.

46. Wathen, T.A.& Caffey, Hugh. *Shifting the Blame: A Report on Sudden Acceleration in the Audi 5000.* New York: The New York Public Interest Research Group, 1987.

47. Zaichowsky, Judith, and Liefeld, J.P., "Personality Profiles of Consumer Complaint Letter Writers," in *Consumer Satisfaction, Dissatisfaction, and Complaining Behavior*, ed. Ralph L. Day. Bloomington, IN: Bureau of Business Research, Indiana University, 1977.

APPENDIX E

Cruise Control, Braking and Electrostatic Discharge Tests Conducted By The Vehicle Research and Test Center

Background Intermittent failures in cruise controls have frequently been suggested as a possible cause of sudden acceleration. Two fundamentally different types of failures are possible: (1) Intermittent shorts or opens in or near the output stage(s) could possibly drive the output to the WOT condition as fast as the servo unit is capable of responding. Mats Gunnerhed describes this type of failure in an older analog type controller in which a single-point open-circuit can produce this result. (Reference 32) (2) Intermittent connections in the speed-sensing circuitry or intermediate processing stages could conceivably generate electrical noise which could be interpreted as a valid speed signal above the minimum value so that if the driver happened to bump the set or resume controls, the cruise control might engage or "resume" to a previously set speed even though the vehicle was actually stopped or travelling very slowly. This second type of failure would normally produce slower throttle opening than the first because the control logic does not generally permit 100% duty-cycles in the drive circuitry for the servo.

If such failures could occur, the question naturally arises as to how far and how fast a car might move as a result. If the driver were actually pressing hard on the brake pedal as soon as the incident began, as most have claimed, how long would it take to stop?

Because of questions about the braking performance of rear-wheel-drive cars (see Section 3.1.5 of the body of this report), it was decided to make various measurements of stopping distances on these cars during the same test sessions as the cruise-control tests.

A third possible explanation for sudden acceleration is malfunction of cruise controls as a result of interference from strong electromagnetic fields. One of the most effective techniques for determining the susceptibility of any piece of electronic equipment to such fields is the use of an electrostatic discharge simulator. Such devices are designed to generate high voltages, typically 25,000 maximum, but with discharge energies limited to a few hundred milli-Joules, so that they are not unduly hazardous to test technicians. Within the immediate vicinity of their discharge adapters they can produce E-fields several orders of magnitude greater than nearby radio transmitters. Because of the very rapid rise time of the discharge current, typically a few nanoseconds, the peak currents approach 100 Amperes. Thus with appropriate adapters, these devices can also generate intense magnetic fields, on the order of several hundred Amperes per meter. The rapid rise-time of a spark discharge also happens to produce a waveform which is mathematically equivalent to the sum of an infinite number of single-frequency sources covering the entire radio-frequency spectrum. Hence, the ESD technique is very widely employed throughout the electronics industry.

Professor Shuichi Nitta of Tokyo University of Agriculture and Technology has reported that at least one type of cruise-control used by Nissan is subject to a throttle-opening malfunction in response to the discharge of 10 kV sparks near the cruise-control wiring harness. (Reference 25)

Objectives

The objectives of these tests were simply to characterize the behavior of each of several passenger cars with relatively high SA-complaint rates under simulated cruise control failures. The characteristics of interest were acceleration, speed, distance, pedal force required to stop, etc., as described in the following section on procedure. Braking and ESD tests were carried out at the same sessions.

Procedures and Results

Procedures and results are contained in the two memoranda prepared by VRTC which follow. The first describes the tests on the two Audi 5000s, while the remaining eight vehicles are covered in the second. Figures E-1 through E-5 contain photos of the instrumentation used in these tests.

Figure E-1: Instrumentation recorder and displays.

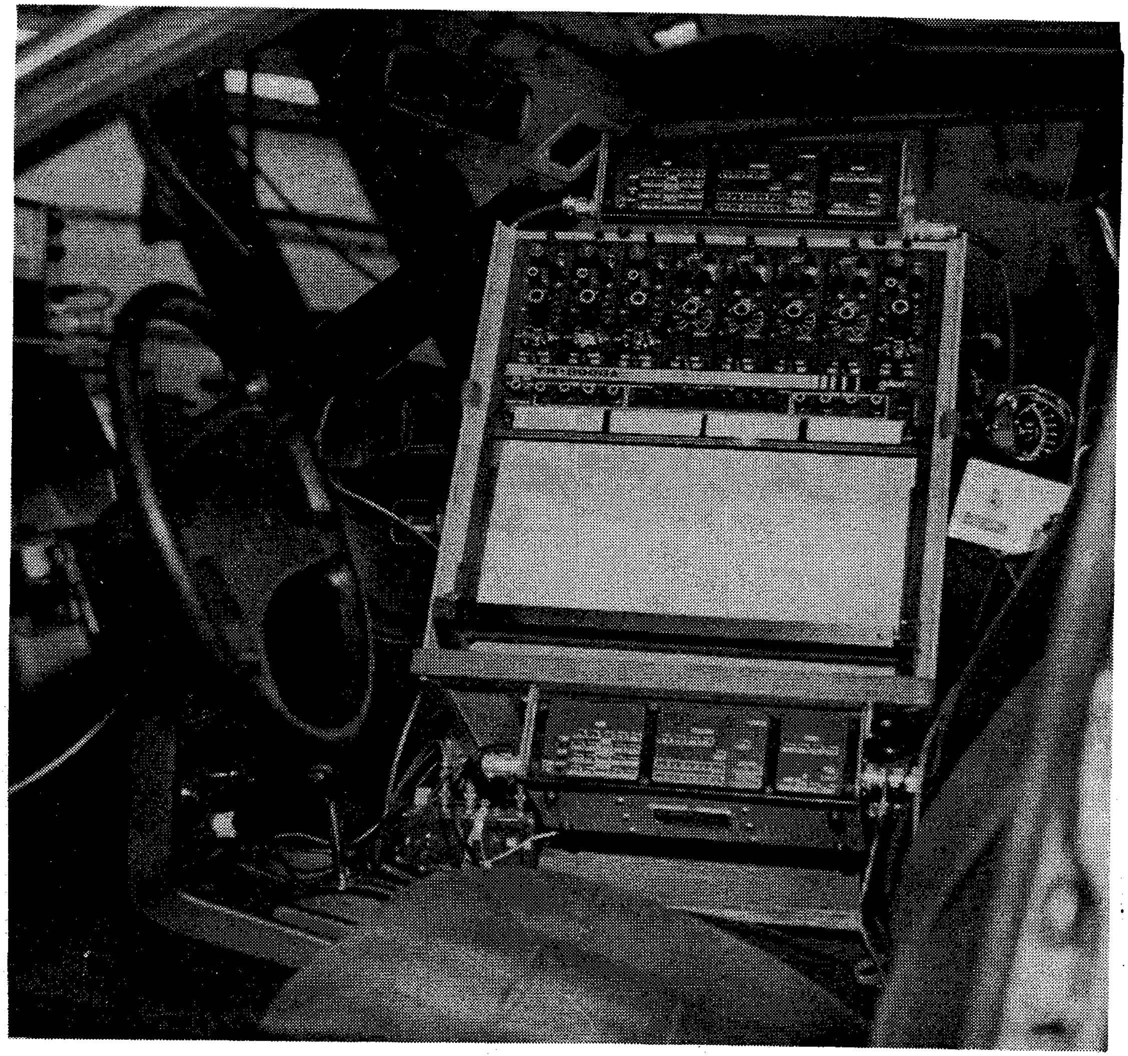


Figure E-2: Modified cruise control is shown mounted just below dash board. The brake pedal force transducer reading is displayed on the large meter above the speedometer.

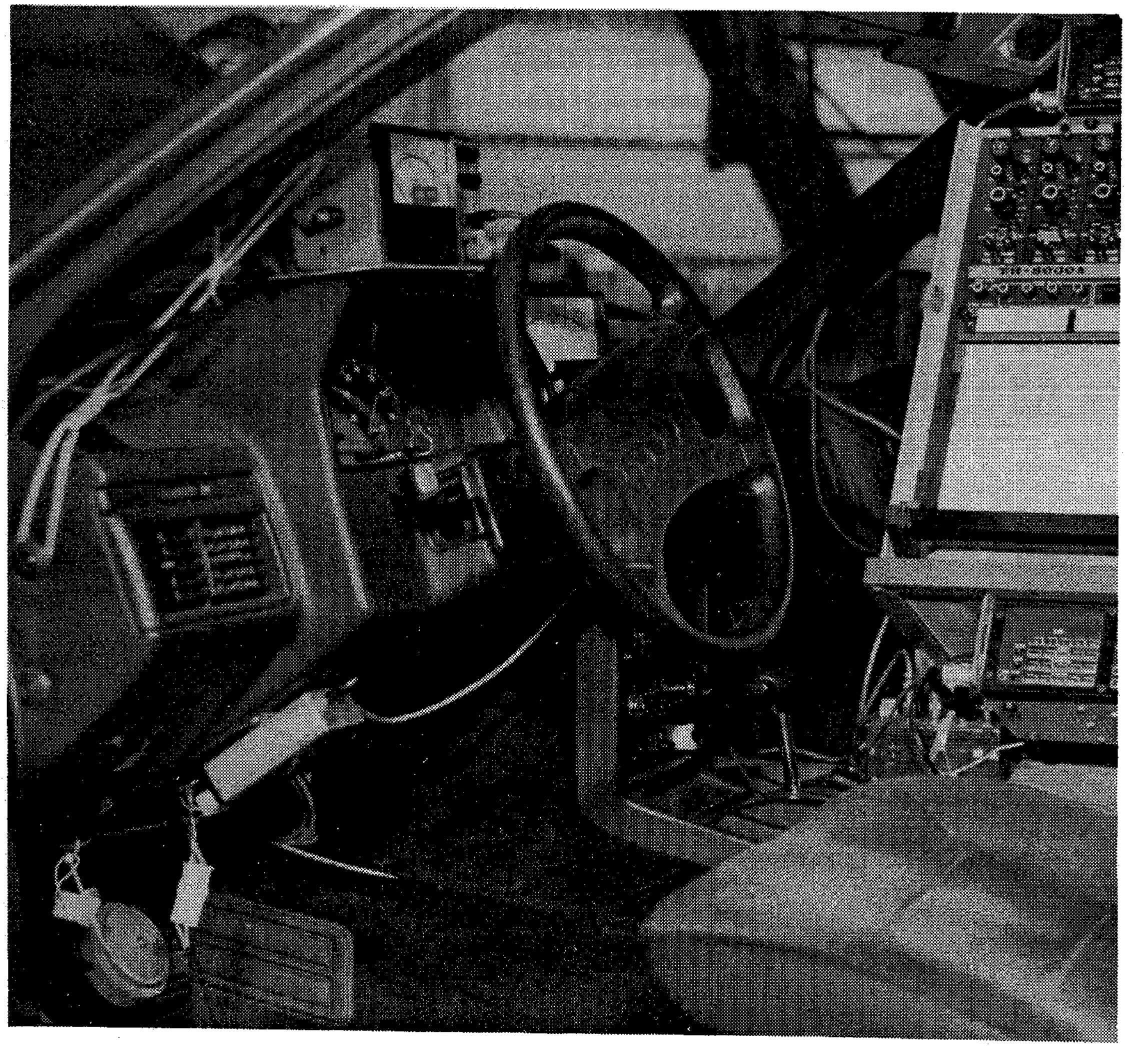


Figure E-3: The fifth wheel is pivoted at the side so that it can readily be used in both forward and reverse.

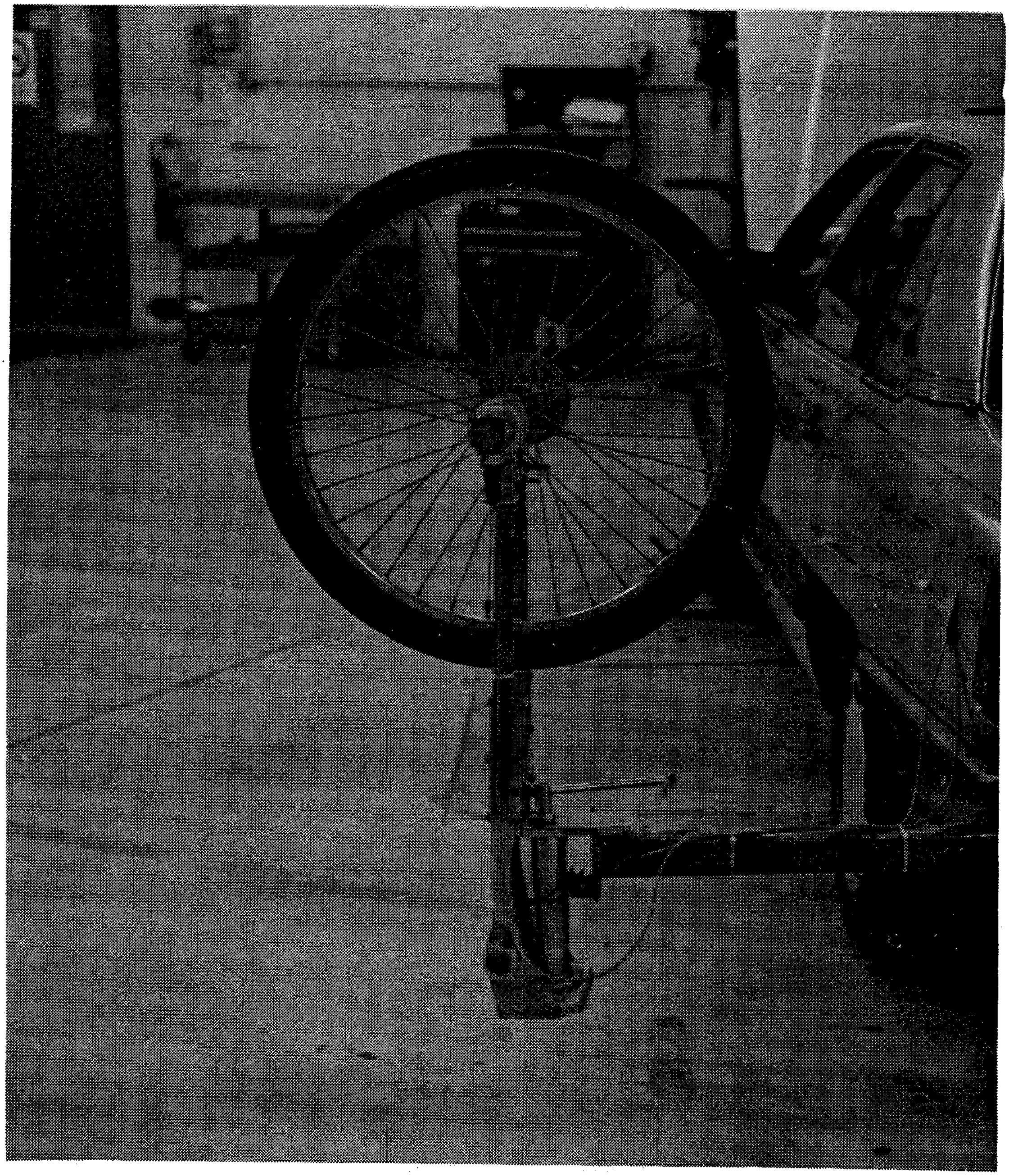


Figure E-4: The throttle-position sensor is the small cylindrical device near the center of this photo with the white cable attached. The vacuum servo is slightly to the right of center.

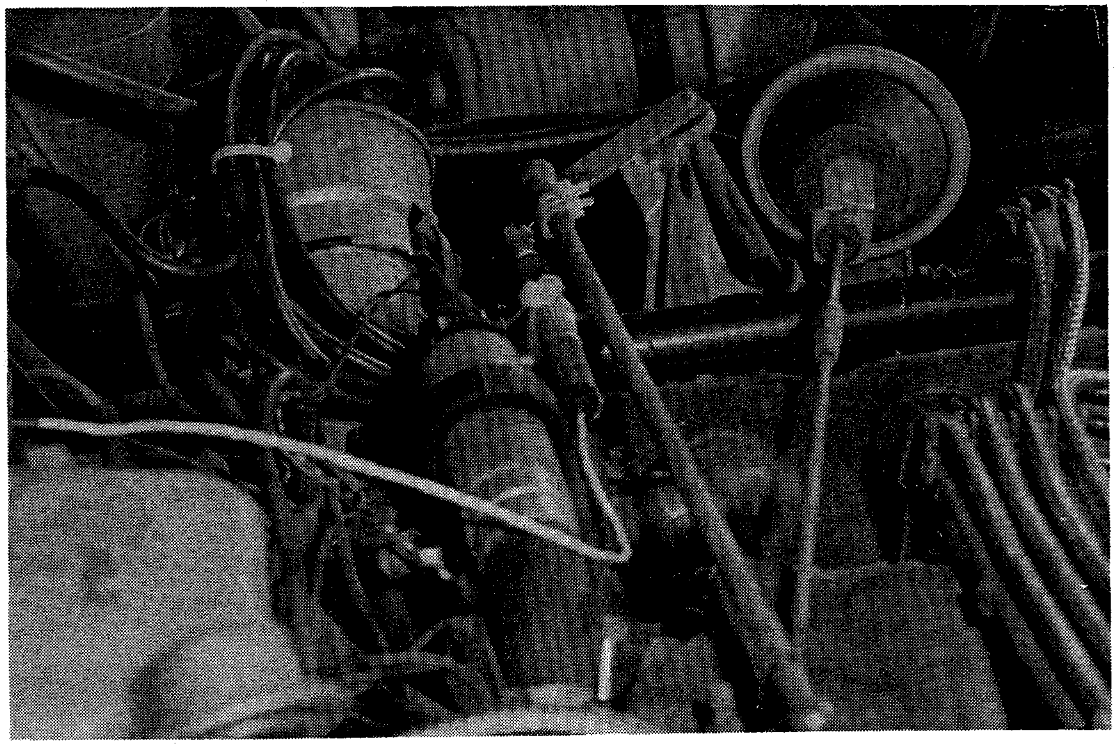
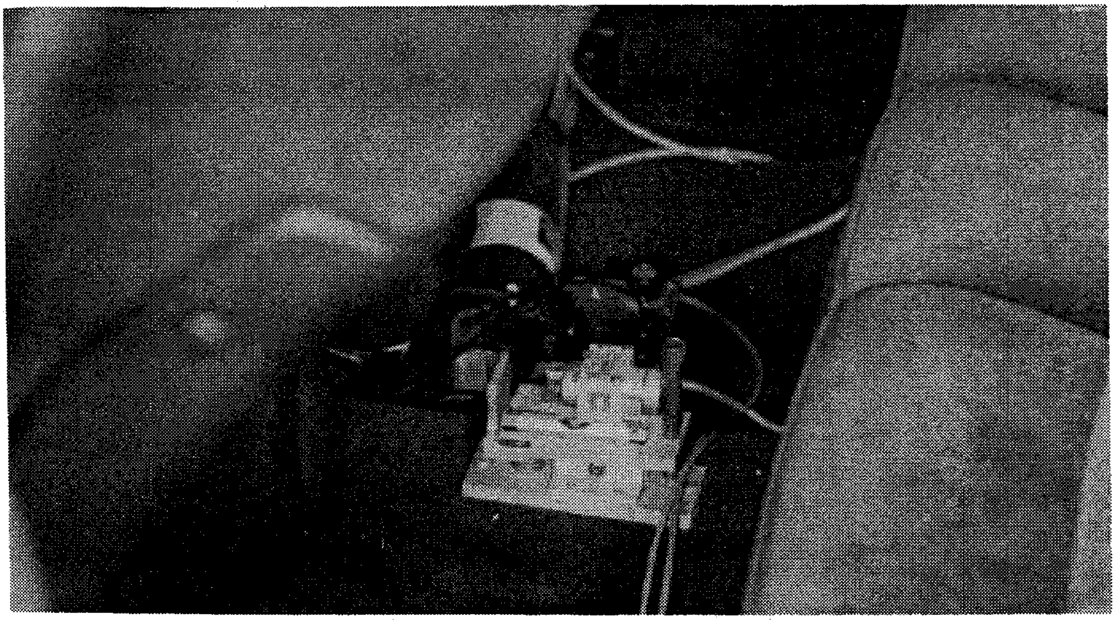


Figure E-5: The accelerometer is bolted firmly to the car body.



U.S. Department of Transportation
National Highway Traffic Safety Administration

Memorandum

Vehicle Research and Test Center
P. O. Box 37
East Liberty, Ohio 43319
(513) 666-4511

Subject: MEMORANDUM REPORT - VRTC-7-8-0128
Cruise Control and Braking Tests
on Audi 5000 Vehicles

Date: NOV 3 1988

From: James E. Hofferberth, Director
Vehicle Research and Test Center

Reply to Attn. of: NRD-20

To: John Pollard, DTS-45
Transportation Systems Center

1.0 INTRODUCTION

This memorandum is a report concerning tests on two Audi 5000 vehicles, owned by the National Highway Traffic Administration (NHTSA), at the Vehicle Research and Test Center (VRTC). The tests described in this report were performed in response to a request from the Transportation Systems Center (TSC), Research and Special Programs Administration (RSPA). The TSC is conducting an investigation for the Office of Defects Investigation (ODI), National Highway Traffic Safety Administration (NHTSA) concerning alleged sudden acceleration on certain vehicles with automatic transmissions. As part of these investigations, the TSC wanted cruise control and braking tests on various vehicles with high sudden acceleration complaint rates.

2.0 Discussion

The purpose of this test program was to test several passenger vehicles with automatic transmissions to determine vehicle performance (acceleration and stopping) with simulated cruise control failures, to determine braking performance in both Drive and Reverse for the Audi 5000 and some rear-wheel-drive (RWD) vehicles, and to determine the effects of electro-static discharge (ESD) on cruise control systems.

This test program was done in four parts; cruise-control tests on Audi 5000 vehicles, cruise-control performance in other vehicles, braking tests on the Audi 5000 and some RWD vehicles, and effects of ESD on cruise control systems. This report covers only the tests on the 1982 and the 1984 Audi 5000 vehicles owned by NHTSA. The primary purpose of this part of the test was to determine how rapidly the Audi 5000 vehicles can accelerate from a stationary position if the cruise control system was to malfunction and begin to open the throttle as soon as the driver shifted the transmission into Drive. Tests included measuring the acceleration by normal idle induced "creep", when the gas pedal was floored, and when cruise control system failures were simulated. Braking tests with various brake application delay times and pedal forces were also conducted. In addition, braking tests from 30 mph in both Drive and Reverse with the throttle wide open and closed and ESD tests were conducted for both test vehicles.

2.1 Test Vehicles

The vehicles tested were two Audi 5000 vehicles owned by NHTSA. One was a 1982 model (VIN WAUGB043XCN061065) with an odometer reading of 53,348 miles and the other was a 1984 model (VIN WAUFB0444EN099818) with an odometer reading of 41,743 miles. Proper engine, brake, and general vehicle performance were verified prior to the test. Idle speed was also verified to be within specifications. TSC prepared modified cruise control units for both the 1982 and the 1984 Audi test vehicles. Each unit was fitted with toggle switches so that when all of the switches were set to "off", the unit functioned normally. For both the 1982 (analog) controller and the 1984 (microprocessor) version, the following switched test conditions were used:

1 - Direct short of the vacuum pump and vacuum dump valve to ground (worst case).

2 - Fault in minimum speed circuit permitting "resume" from a standstill. TSC provided a signal generator for the false speed signal.

The brake-pedal-actuated vacuum-dump switch remained in place and functional for these tests. Instrumentation was installed to record vehicle speed, acceleration, distance traveled, throttle position, engine rpm, brake pedal force, and cruise control system vacuum as a function of time. The interior volume of the cruise control vacuum system was not significantly changed by adding a vacuum transducer for measurements.

2.2 Test Equipment

8 Channel Recorder	GULTON Model TR800
Inverter	NOVA 500 Watt
Servo-Accelerometer	KISTLER Model 305
Pedal Force Meter	GSE Model 3100
Performance Monitors	LABECO Model 625
0-15 psi Pressure Transducer	BELL & HOWELL Model 4-424-0001
Linear Position Potentiometer	BOURNS 3-Inch (Throttle Pos.)
5th Wheel	TRACK TEST
Tach Generator	WESTON Model 750
Timer Control Box	VRTC Special Fixture
VHS-C Video Camera	GENERAL ELECTRIC Model 9-9709
35 mm Camera	MINOLTA SRT200

2.3 Test Procedures

Each test vehicle was tested using the test procedure/data forms shown in the Appendix. The engine was warmed to normal operating temperature for the tests. Tests were conducted on the Vehicle Dynamics Area and an adjacent area with a nominal skid number of 80. Test Series 1 (gas pedal floored), Series 2 (normal idle induced "creep"), and Series 3 (simulated cruise control malfunctions) were non-braking tests. For the minimum speed circuit fault or "spontaneous resume" condition, the transmission had to be left in Drive and the test initiated by a special "false speed signal" circuit supplied by TSC.

Test Series 4 (throttle wide open during stop), Series 5 (throttle closed during stop), Series 6 (vacuum pump/dump valve failure), and Series 7 (minimum speed circuit fault) were braking tests in which the brakes were applied after approximately 1 and 2 seconds and with pedal forces of approximately 60, 100, and 150 lb for each series. The driver's foot was used to supply the brake pedal force. Some tests were not made at 150 lb pedal force if wheel lockup was present at 100 lb.

Test Series 8 was made to determine the minimum brake pedal force (applied in Park and then maintained after shifting to Drive) to prevent the cruise control from causing the vehicle to move when the cruise control pump started (shorted to ground) and the dump valve was plugged.

Test Series 9 (throttle closed during stop) and Series 10 (throttle wide open during stop) were braking tests in both Drive and Reverse to determine the minimum stopping distance from 30 mph.

Test Series 11 were braking tests in both Drive and Reverse for a 0.33 g (10.7 fpsps) stop from 30 mph with the throttle closed (normal) and wide open. Finally, braking tests were run in both Drive and Reverse from 30 mph with the throttle wide open and the same braking force as applied in the original normal stop.

Test Series 12 were ESD tests, a literally a point-and-shoot procedure on the piece of wiring harness that runs to the cruise control. The object is to see if the cruise controls can be caused to exhibit intermittent throttle opening by applying a magnetic field or 25,000 volt spark to the wiring harness. TSC delivered the ESD simulator gun to VRTC and participated in the testing at VRTC for these two test vehicles. For these test vehicles, an ESD spark was also applied directly to the case of the cruise control computer module.

3. Test Results

Copies of the individual data sheets for the two Audi 5000 test cars are included in the Appendix. The chart recorder data will be forwarded to TSC. For Test Series 1 (gas pedal floored), the test vehicles required about 5 seconds to reach 30 mph. For Series 2 (normal idle induced "creep"), the test vehicles required over 20 seconds to reach 100 ft with a final speed of about 5 mph. For Series 3 (simulated cruise control malfunctions), the test vehicles required about 7 seconds to reach 30 mph for "worst case" and varied widely for the minimum speed circuit fault depending on how the "false speed signal" was interpreted by the cruise control module.

When the brakes were applied with a pedal force of approximately 60 lb after a 2-second delay (worst case) after throttle opening, stopping distance was generally less than 20 ft and total distance traveled was about 40 ft whether the gas pedal was floored during stop or only floored prior to the stop. With a pedal force of approximately 60 lb after a 2-second delay after simulating a cruise control failure of the vacuum pump/dump valve (power on), stopping distance was generally less than 10 ft and total distance traveled was about 20 ft. Stopping distance was also less than 10 ft for the minimum speed circuit fault.

The minimum brake pedal force (applied in Park and then maintained after shifting to Drive) to prevent the cruise control from causing the vehicle to move when the cruise control pump started (shorted to ground) and the dump valve was plugged was approximately 50 lb.

The average minimum stopping distance from 30 mph was approximately 50 ft or less (met FMVSS 105) in Drive whether the throttle was wide open or closed during the stop. In Reverse, the average minimum stopping distance from 30 mph was approximately 50 to 60 ft with the throttle closed and approximately 60 to 70 ft with the throttle held wide open during the stop.

For a normal 0.33 g (10.7 fpsps) stop from 30 mph, the stopping distance from 30 mph was less than 100 ft with a pedal force of 20 to 30 lb in Drive or Reverse. When the throttle was held wide open during a 0.33 g stop, the pedal force increased to about 40 to 50 lb although the stopping distance also increased to about 120 ft, indicating a somewhat lower deceleration rate. Neither test vehicle would stop in Drive and Reverse from 30 mph with the throttle held wide open and at the same braking force as applied in the original normal stop.

Applying a magnetic field or 25,000 volt spark to the piece of wiring harness that runs to the cruise control did not cause the cruise control system of either test vehicle to exhibit intermittent throttle opening. The cruise control computer module from the 1982 Audi failed to operate after a spark was applied directly to the case of the cruise control computer modules. This module was sent to TSC for analysis.

'82 Audi

TEST PROCEDURE FOR 1982 AUDI

Chart recorder for speed, acceleration, rpm, brake pedal force, cruise control (c/c) vacuum, throttle position, and event versus time at 10 mm/sec. Engine at normal operating temperature for all tests.

Series 1 - C/C off; Gas pedal floored after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

Run Number	1	2	3
Time to 30 mph (44 fps)	4.9 sec	4.8	4.7
Total Distance Traveled	125.8 ft	124.9	123.7

Series 2 - C/C off; Normal idle induced creep after shifting to Drive. Go to 100 ft. Repeat twice for a total of 3 runs.

Run Number	4	5	6
Time to 100 ft	21.4 sec	21.1	21.6

Series 3 - C/C malfunctions after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

A) Direct short to ground of c/c vacuum pump and dump valve.

Run Number	7	8	9	10
Time to 30 mph	7.0 sec	6.8	6.3	6.4
Total Distance Traveled	177.1 ft	176.3	156.8	158.

B) Minimum speed circuit fault (Actuate Resume in Drive with a 65 mph signal). (Frequency @ 105) -105

Run Number	11	12	13
Time to 30 mph	6.8 sec	7.7	9.4
Total Distance Traveled	160.8 ft	199.5	255.9

Repeat B) with 130 mph signal. (Frequency @ 210) -210

Run Number	14	15	16	17
Time to 30 mph	7.5 sec	8.0	7.6	7.3
Total Distance Traveled	195.3 ft	218.2	194.7	194.4

18
8.0 sec
218.2 ft

'82 Audi

Series 4 - C/C off; Gas pedal floored after shifting to Drive and until vehicle stops. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	20	19	23
Time to Stop	1.4	1.6	1.2
Speed at Brake Applied	13.4	13.0	13.0
Distance after Applied	16.3	17.3	13.0
Total Distance Traveled	39.3	39.7	34.9

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	21	22	24
Time to Stop	1.5	1.0	1.0
Speed at Brake Applied	12.2	8.9	12.3
Distance after Applied	17.0	10.6	12.4
Total Distance Traveled	36.6	22.5	33.7

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	27	25	29
Time to Stop	0.9	0.8	0.7
Speed at Brake Applied	4.3	5.7	6.3
Distance after Applied	6.0	6.0	5.9
Total Distance Traveled	9.4	10.8	11.4

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	28	26	30
Time to Stop	1.2	0.7	0.8
Speed at Brake Applied	5.4	4.9	6.3
Distance after Applied	8.9	5.1	6.6
Total Distance Traveled	13.3	8.9	12.4

'82 Audi

Series 5 - C/C off; Gas pedal floored after shifting to Drive but release throttle when brakes are applied at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	32	31	35
Time to Stop	1.7	1.0	0.8
Speed at Brake Applied	13.1	14.2	13.8
Distance after Applied	20.2	15.3	11.5
Total Distance Traveled	41.9	39.1	36.2

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	33	34	36
Time to Stop	1.3	1.1	0.9
Speed at Brake Applied	13.0	13.0	13.3
Distance after Applied	16.8	14.5	11.4
Total Distance Traveled	39.1	35.5	32.4

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	39	37	41
Time to Stop	0.6	0.6	0.6
Speed at Brake Applied	7.4	5.9	8.3
Distance after Applied	5.6	5.0	5.1
Total Distance Traveled	11.6	10.1	13.0

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	40	38	42
Time to Stop	0.6	0.7	0.6
Speed at Brake Applied	6.7	7.1	7.8
Distance after Applied	5.4	6.4	5.8
Total Distance Traveled	10.6	12.6	14.7

'82 Audi

Series 6 - C/C malfunction (Direct short to ground of c/c vacuum pump and dump valve) after shifting to Drive. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	45	43	47
Time to Stop	0.8	0.6	0.6
Speed at Brake Applied	7.5	7.5	8.5
Distance after Applied	6.9	5.6	6.3
Total Distance Traveled	—	14.2	15.9

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	46	44	48
Time to Stop	0.8	0.6	0.6
Speed at Brake Applied	7.4	7.3	8.6
Distance after Applied	7.9	6.3	6.5
Total Distance Traveled	17.1	—	16.4

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	51	49	53
Time to Stop	0.3	0.3	0.3
Speed at Brake Applied	1.0	1.5	2.7
Distance after Applied	0.9	1.2	1.4
Total Distance Traveled	1.7	2.4	2.9

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	52	50	54
Time to Stop	0.6	0.4	0.2
Speed at Brake Applied	4.2	2.7	1.8
Distance after Applied	3.6	2.4	0.9
Total Distance Traveled	~~2.4~~	4.7	2.1

'82 Audi

Series 7 - C/C malfunction (Minimum speed circuit fault). Actuate Resume in Drive with a 65 mph signal. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	55	*56	59
Time to Stop	0.3	0.7	0.2
Speed at Brake Applied	2.7	7.3	3.4
Distance after Applied	1.1	6.4	1.1
Total Distance Traveled	~~0.2~~	15.7*	~~0.2~~

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	57	58	60
Time to Stop	0.4	0.3	0.3
Speed at Brake Applied	3.4	3.3	3.5
Distance after Applied	1.6	1.1	1.2
Total Distance Traveled	~~0.4~~	~~0.2~~	~~0.4~~

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	61	63	65
Time to Stop	0.2	0.1	0.1
Speed at Brake Applied	1.3	1.2	1.4
Distance after Applied	0.5	0.3	0.5
Total Distance Traveled	~~0.2~~	~~0.2~~	~~0.2~~

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	62	64	66
Time to Stop	0.2	0.1	0.1
Speed at Brake Applied	1.6	1.3	1.6
Distance after Applied	0.5	0.4	0.5
Total Distance Traveled	~~0.2~~	~~0.2~~	~~0.2~~

* See chart. Vac level high.

82 Audi

Series 8 - C/C malfunction - direct short to ground of c/c vacuum pump but dump valve vacuum plugged. Determine minimum brake pedal force to prevent vehicle movement after shifting to Drive. Apply brakes in Park and maintain that level after shifting to Drive.

Brake Pedal Force	50	40	45		
Stopped in Drive	yes	no	yes		

Brake Pedal Force					
Stopped in Drive					

Conversion Reference (mph x 1.6093 = km/h):

MPH	20	25	30	35	40	45	50	55	60	65
KM/HR	32	40	48	56	64	72	80	89	97	105

Series 9 - Measure minimum stopping distance from 30 mph (wheel lockup OK).

In <u>Drive</u>:

Run Number	67	68	69
Time to Stop (sec)	1.6	1.6	1.5
Speed at Brake Applied	30.0	30.3	30.5
Distance after Applied	36.0	37.2	36.1
Pedal Force	144.	134.	80.0

In <u>Reverse</u>:

Run Number	70	71	72
Time to Stop (sec)	2.2	2.3	2.2
Speed at Brake Applied	29.6	29.3	29.5
Distance after Applied	50.6	50.2	50.4
Pedal Force	60.	56.	50-60
	mild lockup	some lockup	slid front tires

82 Audi

13

Series 10 - Repeat Series 9 but hold throttle wide open.

whatever it takes but st under 200. (
1 @ 150

In **Drive**:

Run Number	73	74	75
Time to Stop (sec)	2.0	2.0	2.0
Speed at Brake Applied	32.3	32.4	32.2
Distance after Applied	50.6	52.4	51.9
Pedal Force	180.	180-200	160-180

In **Reverse**:

Run Number	76	77	78
Time to Stop (sec)	2.4	2.5	2.4
Speed at Brake Applied	31.2	31.7	30.8
Distance after Applied	58.5	63.7	60.4
Pedal Force	140.	100.	120.

estimate 30° spin on Reverse stops

Series 11 - A) Measure stopping distance and pedal force from 30 mph for a 10.7 ft/sec/sec deceleration.

In **Drive**:

Run Number	79	80	81
Time to Stop (sec)	4.1	4.0	4.1
Speed at Brake Applied	30.1	30.0	30.3
Distance after Applied	98.0	94.5	97.7
Pedal Force	28.	30.	28.

In **Reverse**:

Run Number	82	83	84	85
Time to Stop (sec)	4.2	3.8	4.3	4.0
Speed at Brake Applied	29.2	28.6	29.3	29.5
Distance after Applied	96.1	82.4	98.5	91.2
Pedal Force	24.	28.	28.	26.

86

82 Ford!

Series 11 - B) Measure pedal force for a 30 mph with a 10.7 ft/sec/sec deceleration (same stopping distance as A) but hold the throttle wide open.

In Drive:

Run Number	86	87	88
Time to Stop (sec)	4.6	4.6	4.8
Speed at Brake Applied	31.8	32.2	32.2
Distance after Applied	117.4	116.8	126.4
Pedal Force	50.	50.	60.

In Reverse:

Run Number	89	90	91
Time to Stop (sec)	5.1	4.4	4.8
Speed at Brake Applied	31.8	31.9	31.6
Distance after Applied	137.7	111.0	123.3
Pedal Force	50.	44.	46

Series 11 - C) Measure stopping distance from 30 mph with the throttle held wide open but the same pedal force as measured in Series 11 - A).

In Drive:

	Run Number	96	97	98
	Time to Stop (sec)	7.5	8.1	8.5
	Speed at Brake Applied	32.5	32.9	32.6
	Distance after Applied	144.8	148.3	152.4
28-30	Pedal Force	50 *	50	50

In Reverse:

	Run Number	92	93	94	95
	Time to Stop (sec)	8.4	8.5	8.2	8.5
	Speed at Brake Applied	31.5	31.4	32.4	31.9
	Distance after Applied	183.6 **	192.0	177.8	183.3
26	Pedal Force	30.	40	40	40

Series 12 - Electro-Static Discharge Tests - Identify which piece of wiring harness goes to the cruise control. Point-and-Shoot procedure to be used.

** Vehicle wouldn't stop for 2nd attempt at 30lb Pedal Force

* 40lb wouldn't stop vehicle in Drive.

'84 Audi

TEST PROCEDURE FOR 1984 AUDI

Chart recorder for speed, acceleration, rpm, brake pedal force, cruise control (c/c) vacuum, throttle position, and event versus time at 10 mm/sec. Engine at normal operating temperature for all tests.

Series 1 - C/C off; Gas pedal floored after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

Run Number	1	2	3
Time to 30 mph (sec)	5.4	5.2	5.3
Total Distance Traveled	134.7 ft	131.9	133.7

Series 2 - C/C off; Normal idle induced creep after shifting to Drive. Go to 100 ft. Repeat twice for a total of 3 runs.

Run Number	4	5	6
Time to 100 ft	20.8	20.8	21.0
	sec	Final Speed < 5mph	

Series 3 - C/C malfunctions after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

A) Direct short to ground of c/c vacuum pump and dump valve.

Run Number	7	8	9 *
Time to 30 mph (sec)	6.5	6.6	6.9
Total Distance Traveled	155.2 ft	156.0	159.2

B) Minimum speed circuit fault (Actuate Resume in Drive with a 65 mph signal). (Frequency @ 105) ~105

41	42**	Run Number	37	38	39	40
13.1	13.7	Time to 30 mph (sec)	15.3	15.0	12.4	10.8
374.5	397.4	Total Distance Traveled	417.4 ft	439.6	345.6	299.3

Repeat B) with 30 mph signal. (Frequency @ 210) ~210

Run Number	50	51	52	53 ***
Time to 30 mph (sec)	6.3	6.2	6.8	7.2
Total Distance Traveled	164.6 ft	160.7	177.1	184.4

* Run 10 (chart) on page 2.

** Run 43 on page 4.

*** Run 54 on page 5.

84 Audi

Series 4 - C/C off; Gas pedal floored after shifting to Drive and until vehicle stops. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	60 (2sec/~~100lb~~)		60 (2sec/~~150lb~~)	
Run Number	10	11	12	13	14
Time to Stop	1.2	1.4	1.4	1.4	1.1
Speed at Brake Applied	14.	12.	14.	13.	14.5
Distance after Applied	10.9	13.3	14.5	15.1	13.7
Total Distance Traveled	32.3	34.2	35.	34.5	37.7

	100 (2sec/~~50lb~~)		(2sec/100lb)		(2sec/150lb)		
Run Number	15	16	17	18	19	20	2
Time to Stop	1.5	1.0	1.1	1.0	1.2	1.1	1.
Speed at Brake Applied	14.	12.	13.5	13.5	14.	13.5	12.
Distance after Applied	12.1	8.2	10.6	9.2	11.1	10.2	9.
Total Distance Traveled	34.0	25.4	31.7	29.	35.5	31.3	27.

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	22	24	26
Time to Stop	0.9	1.2	0.8
Speed at Brake Applied	7.0	8.5	9.0
Distance after Applied	4.4	6.1	5.8
Total Distance Traveled	10.2	13.0	13.4

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	23	25	
Time to Stop	0.9	0.7	
Speed at Brake Applied	7.0	7.0	
Distance after Applied	5.0	4.5	
Total Distance Traveled	10.3	9.3	

84 Audi

Series 5 - C/C off; Gas pedal floored after shifting to Drive but <u>release throttle when brakes are applied</u> at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	27	29	
Time to Stop	1.2	1.1	Got wheel lock up at 100 lb. P.F.
Speed at Brake Applied	14.0	14.5	
Distance after Applied	11.8	11.6	
Total Distance Traveled	34.7	35.3	

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	28	30	
Time to Stop	1.3	1.0	
Speed at Brake Applied	14.5	13.5	
Distance after Applied	13.7	9.0	
Total Distance Traveled	37.0	29.3	

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	33	31	35
Time to Stop	1.0	0.9	0.9
Speed at Brake Applied	7.5	9.0	9.0
Distance after Applied	5.9	6.8	6.1
Total Distance Traveled	11.1	14.3	14.7

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	34	32	36 *
Time to Stop	0.9	3.2	1.2
Speed at Brake Applied	7.0	9.0	8.5
Distance after Applied	5.2	6.3	5.4
Total Distance Traveled	9.9	14.8	11.9

* Run 37 on page 1

'84 Audi

Series 6 - C/C malfunction (Direct short to ground of c/c vacuum pump and dump valve) after shifting to Drive. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	43	45	46
Time to Stop	1.1	0.8	1.1
Speed at Brake Applied	6.5	7.6	6.7
Distance after Applied	7.7	5.0	4.3
Total Distance Traveled	16.4	12.0	11.9

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	44	48	47
Time to Stop	0.9	1.2	0.8
Speed at Brake Applied	7.4	8.0	7.0
Distance after Applied	8.8	5.9	5.0
Total Distance Traveled	18.6	13.9	12.5

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	49 *		
Time to Stop	0.7		
Speed at Brake Applied	0.9		
Distance after Applied	0.4		
Total Distance Traveled	1.0 ←		

Distance traveled makes further tests unnecessary

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number			
Time to Stop			
Speed at Brake Applied			
Distance after Applied			
Total Distance Traveled			

* Run 50 on page 1

'84 Audi

Series 7 - C/C malfunction (Minimum speed circuit fault). Actuate Resume in Drive with a 65 mph signal. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	54	56	
Time to Stop	0.8	0.8	Front wheel Lockup @ 100lb
Speed at Brake Applied	11.2	11.5	
Distance after Applied	7.4	7.3	
Total Distance Traveled	33.4	35.0	

	(2sec/60lb)	(2sec/100lb)	(2sec/150lb)
Run Number	55	57	
Time to Stop	0.9	0.9	
Speed at Brake Applied	11.8	12.5	
Distance after Applied	7.8	7.7	
Total Distance Traveled	37.3	37.5	

	(1sec/60lb)	(1sec/100lb)	(1sec/150lb)
Run Number	59	58	
Time to Stop	1.0	0.8	
Speed at Brake Applied	8.8	7.4	
Distance after Applied	5.3	4.6	
Total Distance Traveled	16.0	14.7	

	(1sec/60lb)	(1sec/100lb)		(1sec/150lb)	
Run Number	60	61	62	63	64
Time to Stop	0.9	1.2	1.3	0.9	1.1
Speed at Brake Applied	7.6	7.9	8.0	8.3	8.0
Distance after Applied	5.1	5.3	5.7	5.2	4.7
Total Distance Traveled	16.2	15.7	16.3	17.0	15.0

'84 Audi

Series 8 - C/C malfunction - direct short to ground of c/c vacuum pump but dump valve vacuum plugged. Determine minimum brake pedal force to prevent vehicle movement after shifting to Drive. Apply brakes in Park and maintain that level after shifting to Drive.

A.	Brake Pedal Force	52	50	40		
	Stopped in Drive	Yes	creeped	moved		
B.	Brake Pedal Force	50	40	45	48	
	Stopped in Drive	yes	creeped	creeped	yes	

Conversion Reference (mph x 1.6093 = km/h):

MPH	20	25	30	35	40	45	50	55	60	65
KM/HR	32	40	48	56	64	72	80	89	97	105

A = Parking lot, warm brakes.

B = Garage floor, cold brakes.

10-26-87

84 Audi

Series 8 - C/C malfunction - direct short to ground of c/c vacuum pump but dump valve vacuum plugged. Determine minimum brake pedal force to prevent vehicle movement after shifting to Drive. Apply brakes in Park and maintain that level after shifting to Drive.

Brake Pedal Force					
Stopped in Drive					

Series 9 - Measure minimum stopping distance from 30 mph (wheel lockup OK).

In Drive:

Run Number	65	66	67
Time to Stop (sec)	1.8	1.8	2.0
Speed at Brake Applied	30.5	30.3	30.3
Distance after Applied	44.9	43.5	46.5
Pedal Force	60. max	60. max	60. max
	mild lockup @ end of stop	mild lockup	one wheel lockup @ end. L.F.

Avg 45'

In Reverse:

Run Number	68	69	70
Time to Stop (sec)	2.5	2.8	2.5
Speed at Brake Applied	29.8	30.2	30.0
Distance after Applied	56.8	65.1	59.3
Pedal Force	40. max	38. max	42. max
	LF lockup @ end of stop.	↲ same mild	↲ same mild

Avg [illegible]

84 Audi

Series 10 - Repeat Series 9 but hold throttle wide open.

In <u>Drive</u>:

Run Number	71	72	73
Time to Stop (sec)	2.0	1.9	2.0
Speed at Brake Applied	32.4	32.9	32.6
Distance after Applied	52.4	49.6	50.8
Pedal Force	120. max	150. max	140. max

In <u>Reverse</u>:

Run Number	74	75	76
Time to Stop (sec)	2.8	2.6	2.8
Speed at Brake Applied	31.9	32.1	31.7
Distance after Applied	72.1	67.7	77.0
Pedal Force	80. max	80. max	60. max
		10-15° spin	

Series 11 - A) Measure stopping distance and pedal force from 30 mph for a 10.7 ft/sec/sec deceleration.

In <u>Drive</u>:

Run Number	77	78	79
Time to Stop (sec)	4.1	4.1	4.2
Speed at Brake Applied	30.3	30.4	30.1
Distance after Applied	96.5	99.7	99.5
Pedal Force	20.	20.	20.

In <u>Reverse</u>:

Run Number	80	81	82	83
Time to Stop (sec)	4.3	3.9	4.2	4.0
Speed at Brake Applied	29.8	29.9	30.0	29.7
Distance after Applied	96.9	86.8	98.8	92.0
Pedal Force	18.	20.	20.	20.
	DH	UH	DH	

4A

84 Audi

Series 11 - B) Measure pedal force for a 30 mph with a 10.7 ft/sec/sec deceleration (same stopping distance as A) but hold the throttle wide open.

In Drive:

Run Number	84	85	86	87
Time to Stop (sec)	4.9	4.8	4.4	4.7
Speed at Brake Applied	32.7	32.2	31.1	32.2
Distance after Applied	128.2	121.4	108.3	124.6
Pedal Force	44. ave.	44. ave	50.*	44 ave

*HIGHER P.F.

AVG. 121'
46

In Reverse:

92	93	Run Number	88	89	90	91
4.3	4.5	Time to Stop (sec)	5.7	5.3	4.4	4.4
31.4	32.2	Speed at Brake Applied	31.6	31.6	31.6	31.3
104.7	112.7	Distance after Applied	140.2	130.2	114.3	106.3
38.	38.	Pedal Force	38.*	38.*	40.	38.

AVG
115
38

* Decel < 10 fpsps

Series 11 - C) Measure stopping distance from 30 mph with the throttle held wide open but the same pedal force as measured in Series 11 - A).

20 lb PF won't stop car ~ 8 mph terminal speed

In Drive:

Run Number	94	95	96
Time to Stop (sec)	7.4	7.9	9.1
Speed at Brake Applied	32.2	33.6	31.9
Distance after Applied	150.7	176.6	170.6
Pedal Force	32.	32.	32.

AVG
166'
[illegible]

20

In Reverse:

Run Number	97	98	99	100
Time to Stop (sec)	6.2	6.9	6.7	6.0
Speed at Brake Applied	31.2	30.5	32.6	31.7
Distance after Applied	139.7	147.5	162.6	139.6
Pedal Force	30.	30.	30.	30.

A
14
3

20

Series 12 - Electro-Static Discharge Tests - Identify which piece of wiring harness goes to the cruise control. Point-and-Shoot procedure to be used.

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

Memorandum

Vehicle Research and Test Center
P. O. Box 37
East Liberty, Ohio 43319
(513) 666-4511

Subject: MEMORANDUM REPORT - VRTC-7-8-0128A
Cruise Control and Braking Tests
on Various Vehicles

Date: DEC 22 1988

From: James E. Hofferberth, Director
Vehicle Research and Test Center

Reply to
Attn. of:

To: John Pollard, DTS-45
Transportation Systems Center

1.0 INTRODUCTION

This memorandum is a report concerning cruise control and braking tests on various vehicles at the Vehicle Research and Test Center (VRTC). The tests described in this report were performed in response to a request from the Transportation Systems Center (TSC), Research and Special Programs Administration (RSPA). The TSC is conducting an investigation for the Office of Defects Investigation (ODI), National Highway Traffic Safety Administration (NHTSA) concerning alleged sudden acceleration on certain vehicles with automatic transmissions. As part of these investigations, the TSC wanted cruise control and braking tests on various vehicles with high sudden acceleration complaint rates.

2.0 Discussion

The purpose of this test program was to test several passenger vehicles with automatic transmissions to determine vehicle performance (acceleration and stopping) with simulated cruise control failures, to determine braking performance in both Drive and Reverse for some rear-wheel-drive (RWD) vehicles, and to determine the effects of electro static discharge (ESD) on cruise control systems.

SAFETY BELTS SAVE LIVES

This test program was done in four parts; cruise control tests on Audi 5000 vehicles, cruise control performance in other vehicles, braking tests on the Audi 5000 and some RWD vehicles, and effects of ESD on cruise control systems. This report does not cover the tests on the Audi 5000 since those tests were covered in a previous report. The primary purpose of this part of the test was to determine how rapidly the subject vehicles can accelerate from a stationary position if the cruise control system was to malfunction and begin to open the throttle as soon as the driver shifted the transmission into Drive. Tests included measuring the acceleration by normal idle induced "creep", when the gas pedal was floored, and when cruise control system failures were simulated. Braking tests with various brake application delay times and pedal forces were also conducted. In addition, braking tests from 30 mph in both Drive and Reverse with the throttle wide open and closed (on some RWD vehicles) and ESD tests (all test cars except the Chrysler and Mercedes) were conducted.

2.1 Test Vehicles

The test vehicles, owned or leased by NHTSA, included the following:

Vehicle Description	Engine Size/Cyl.	Vehicle ID No. (VIN)	Odometer (miles)
1984 Mercury Grand Marquis	5.0L/V-8	1MEBP95F6EZ612727	56,104
1988 Mercedes 300E (ABS)	3.0L/ 6	WDBEA30D3JA579664	18,624
1982 Toyota Cressida	2.8L/ 6	JT2MX62E0C0035028	20,332
1986 Buick Electra (ABS; FWD)	3.8L/V-6	1G4CX69B1G1505433	7,676
1984 Chevrolet Camaro Z28	5.0L/V-8	1G1AP87GXEN117380	60,481
1985 Chrysler New Yorker (FWD,T)	2.2L/I-4	1C3BT56E1FC244302	39,662
1985 Nissan 300ZX	3.0L/ 6	JN1HZ14S4FX097474	33,282
1985 Cadillac DeVille (FWD)	4.1L/V-8	1G6CD6981F4273126	69,779

Notes: ABS = Anti-lock Braking System; FWD = Front-Wheel-Drive; T = Turbo

Proper engine, brake, and general vehicle performance were verified prior to the test. Idle speed was also verified to be within specifications.

TSC prepared modified cruise control units for all the test vehicles except the Chrysler. Each unit was fitted with toggle switches so that when all of the switches were set to "off", the unit functioned normally. The following switched test conditions were used:

1 - Direct short of the vacuum solenoid and regulator valve (electro-mechanical for Mercedes 300E) to ground (worst case).

2 - Fault in minimum speed circuit permitting "resume" from a standstill. TSC provided a signal generator for the false speed signal.

The air bleed port on the servo was blocked to simulate a cruise control failure for the Chrysler New Yorker. The Cadillac cruise control was part of the Engine Control Computer (ECU).

Instrumentation was installed to record vehicle speed, acceleration, distance traveled, throttle position, engine rpm, brake pedal force, and cruise control system vacuum (where applicable) as a function of time. The interior volume of the cruise control vacuum system was not significantly changed by adding a vacuum transducer for measurements.

2.2 Test Equipment

8 Channel Recorder	Gulton Model TR800
Inverter	Nova 500 Watt
Servo-Accelerometer (Accel./Decel.)	Kistler Model 305
Pedal Force Meter	GSE Model 3100
Pedal Force Transducer (On Brake)	GSE Model 4350-300
Performance Monitors (Distance, Time)	Labeco Model 625
0-15 psi Pressure Transducer (Vac.)	Bell & Howell Model 4-424-0001
Linear (Throttle) Position Potentiometer	Bourns 3-Inch
5th Wheel (Vehicle Speed)	Track Test
Tach Generator (Engine Speed)	Weston Model 750
Timer Control Box (Delay Times)	VRTC Special Fixture
VHS-C Video Camera	General Electric Model 9-9709
35 mm Camera	Minolta SRT200

2.3 Test Procedures

Each test vehicle was tested using the test procedure/data forms (through Series 8) shown in the Appendix. The engine was warmed to normal operating temperature for the tests. Tests were conducted on or in an area adjacent to the Vehicle Dynamics Area with a nominal skid number of 80. Test Series 1 (gas pedal floored), Series 2 (normal idle induced "creep"), and Series 3 (simulated cruise control malfunctions) were non-braking tests. For the minimum speed circuit fault or "spontaneous resume" condition (not for the Chrysler), the transmission had to be left in Drive and the test initiated by a special "false speed signal" circuit supplied by TSC.

Test Series 4 (throttle wide open during stop), Series 5 (throttle closed during the stop), Series 6 (failures of vacuum solenoid/regulator valves; electro-mechanical for the Mercedes and Chrysler), and Series 7 (minimum speed circuit fault; not for the Chrysler) were braking tests in which the brakes were applied after approximately 1 and 2 seconds and with pedal forces of approximately 60, 100, and 150 lb for each series. The driver's foot was used to supply the brake pedal force. Some tests were not made at 150 lb pedal force if early wheel-lockup was present at 100 lb.

Test Series 8 was made to determine the minimum brake pedal force (applied in Park and then maintained after shifting to Drive) to prevent the cruise control from causing the vehicle to move with the "worst case" cruise control malfunction and the brake pedal "dump" switch bypassed.

Test Series 9 (throttle closed during stop) and Series 10 (throttle wide open during stop) were braking tests in both Drive and Reverse to determine the minimum stopping distance from 30 mph for some of the <u>RWD</u> test cars.

Test Series 11 were braking tests in both Drive and Reverse for a 0.33 g (10.7 fpsps) stop from 30 mph with the throttle closed (normal) and wide open for some of the <u>RWD</u> test cars. This series also included braking tests in both Drive and Reverse from 30 mph with the throttle wide open and the same braking force as applied in the original normal stop.

Test Series 12 were ESD tests, a literally point-and-shoot procedure on the piece of wiring harness that runs to the cruise control. The object was to see if the cruise control system would cause intermittent throttle opening if a magnetic field or a 20 to 25 KV spark was applied to the wiring harness. With the vehicle drive-wheels off the ground and the transmission in Drive, a set speed command to the cruise control system was entered using the special "false speed signal" circuit supplied by TSC. After a momentary brake application to deactivate the cruise control, the ESD simulator gun was used to determine if a "spontaneous resume" condition could be initiated. Spark was applied only to the vehicle chassis and not to the piece of wiring harness in the Cadillac because of possible damage to the ECU. In this case, with the DeVille drive-wheels off the ground and the transmission in Drive, reaction to the ESD tests was monitored with the engine at idle and cruise control power on and also with a set speed command to the normal cruise control system. The ESD test was not performed on the Mercedes (previous tests by TSC) or the Chrysler (cruise control system was electro-mechanical and did not use a microprocessor). TSC delivered the ESD simulator gun to VRTC and participated in the testing at VRTC for the Mercury Grand Marquis test vehicle. For most test vehicles, an ESD spark was also applied directly to the case of the cruise control computer module.

3. Test Results

Copies of the individual data sheets for the eight test cars are included in the Appendix. An abbreviated summary of the data for each test car is shown in the following tables and serves as the basis for the discussion below. For Test Series 1 (gas pedal floored), the test vehicles required 3.4 to 4.1 seconds to reach 30 mph. For Series 2 (normal idle induced "creep"), the test vehicles required 11.4 to 23.3 seconds to reach 100 ft with final speeds of 3.6 to 9.2 mph. For Series 3 (simulated cruise control malfunctions), the test vehicles required 4.0 to 10.0 seconds for "worst case" and 4.6 to 14.6 seconds for the minimum speed circuit fault to reach 30 mph. For the minimum speed circuit fault, individual vehicle responses varied widely depending on how the "false speed signal" was interpreted by the cruise control module.

When the brakes were applied with a pedal force of approximately 60 lb after a 2-second delay (worst case) after throttle opening, stopping distance was generally less than 50 ft and total distance traveled was 70 ft or less when the gas pedal was floored during stop (Series 4). The one exception was the Camaro Z28 (engine with greatest horsepower) which required 80 ft to stop and covered a total distance of 116 ft. With a brake pedal force of 60 lb after a 2-second delay, stopping distance was 20 ft or less and the total distance traveled was 56 ft or less when the gas pedal was floored until the brakes were applied (Series 5). With a brake pedal force of 60 lb after a 2-second delay while simulating a "worst case" cruise control failure (Series 6), the Camaro had the longest stopping distance of 37 ft and total distance traveled of 78 ft. Stopping distance (33 ft) was also longest for the Camaro during the minimum speed circuit fault tests (Series 7).

The minimum brake pedal force (applied in Park and then maintained after shifting to Drive) to prevent the cruise control from causing the vehicle to move with the "worst case" cruise control failure and the brake pedal dump switch(s) deactivated ranged from 10 to 40 lb (Series 8).

Series 9 through 11 were performed on three (Mercury, Mercedes, and Camaro) RWD test cars. This testing was not requested for the Cressida and was not performed on the Nissan 300ZX because of potential damage to the leased vehicle. The average minimum stopping distance from 30 mph was 43 ft or less (met FMVSS 105) in Drive and 53 ft in Reverse with the throttle closed during the stop (Series 9). The average minimum stopping distance from 30 mph ranged from 81 to 140 ft in Drive and 122 to 239 ft in Reverse when the throttle was held wide open during the stop (Series 10). The longest minimum stopping distance in Reverse (239 ft for the Camaro) was made with a relatively low brake pedal force of 78 lb since higher pedal forces caused the vehicle to spin during the stop.

For a normal 0.33 g (10.7 fpsps) stop from 30 mph (Series 11A), the stopping distances from 30 mph were approximately 100 ft with pedal forces less than 20 lb in Drive or Reverse. When the throttle was held wide open (Series 11B), achieving a 0.33 g stop was difficult, and the stopping distances from 30 mph in Drive varied from 119 to 148 ft (indicating a somewhat lower deceleration rate) with pedal forces ranging from 113 to 137 lb. Achieving a 0.33 g stop in Reverse when the throttle was held wide open was even more difficult and the stopping distances from 30 mph varied from 160 to 388 ft (indicating a much lower deceleration rate) with pedal forces ranging from 128 to 156 lb. In fact, a 200 lb pedal force resulted in only a 7 fpsps deceleration rate for the Mercedes stop in Reverse when the throttle was held wide open. None of three test vehicles would stop in Drive and Reverse from 30 mph with the throttle held wide open and at the same braking force as applied in the original normal stop (Series 11C).

The ESD tests were performed for all the test cars except the Mercedes (previous tests by TSC) and Chrysler (no microprocessor). Applying a magnetic field or a 20 to 25 KV spark to the piece of wiring harness that runs to the cruise control did not cause the cruise control system of any of the test vehicles to exhibit intermittent throttle opening. However, in the case of the DeVille where a 25 KV spark was applied to the alternator case, the engine speed increased slightly because of the Idle Speed Control (ISC) motor reaction.

Abbreviated Summary of Data for the 1984 Mercury Grand Marquis Test Vehicle

Series	Description of Test		Avg. Time to Target (sec)	Average Stopping Distance (ft)	Average Total Distance (ft)	Brake Pedal Force (lb)	Remarks
1	WOT to 30 mph		3.7	N/A	95	N/A	
2	Normal Idle to 100 ft		14.0		6.4 mph @ 100'		
3A	Worst case C/C to 30 mph		5.5		124		
3B	C/C speed fault to 30 mph	Low	14.6		368		105 HZ
	with low/high freq. input	High	6.0		149		210 HZ
4	WOT until stopped		Longest	43	69	Lowest	
5	WOT until brake applied		braking	18	53	P.F.	
6	Worst case C/C until stopped		delay of	18	30	of	
7	C/C speed fault (low freq. input)		2 seconds	9	19	60 lb	105 HZ
8	Min. P.F. to prevent motion						
	for worst case C/C		N/A	N/A	N/A	24-28	
				Minimum			
9	Min. stop from 30 mph in	DR	N/A	43	N/A	150	
	Drive (DR) and Reverse (REV)	REV		49		150	
10	Min. stop from 30 mph	DR		117		149	
	with WOT until stopped	REV		122		157	
				Average			
11A	10.7 ft/s/s decel stop	DR	N/A	96	N/A	16	
	from 30 mph	REV		101		12	
11B	10.7 ft/s/s from 30 mph	DR		137		113	
	with WOT until stopped	REV		160		128	
11C	Stop from 30 mph with WOT	DR		415+		20	Wouldn't Stop-Aborted Run
	and P.F. from 11A	REV		---			
12	Electro-Static-Discharge		N/A	N/A	N/A	N/A	No effect

Notes: C/C = cruise control; WOT = wide open throttle; P.F. = brake pedal force

Abbreviated Summary of Data for the 1988 Mercedes 300E Test Vehicle

Series	Description of Test		Avg. Time to Target (sec)	Average Stopping Distance (ft)	Average Total Distance (ft)	Brake Pedal Force (lb)	Remarks
1	WOT to 30 mph		3.9	N/A	97	N/A	
2	Normal Idle to 100 ft		16.7	5.7 mph @ 100'			
3A	Worst case C/C to 30 mph		10.0		292		
3B	C/C speed fault to 30 mph	Low	10.6		275		120 HZ
	with low/high freq. input	High	7.2		172		240 HZ
4	WOT until stopped		Longest braking delay of 2 seconds	49	70	Lowest P.F. of 60 lb	
5	WOT until brake applied			14	42		
6	Worst case C/C until stopped			9	23		
7	C/C speed fault (low freq. input)			4	11		120 HZ
8	Min. P.F. to prevent motion for worst case C/C		N/A	N/A	N/A	40	
				Minimum			
9	Min. stop from 30 mph in	DR	N/A	42	N/A	65	
	Drive (DR) and Reverse (REV)	REV		53		70	
10	Min. stop from 30 mph	DR		140		155	
	with WOT until stopped	REV		173		165	
				Average			
11A	10.7 ft/s/s decel stop	DR	N/A	99	N/A	16	
	from 30 mph	REV		87		17	
11B	10.7 ft/s/s from 30 mph	DR		148		130	
	with WOT until stopped	REV		206		153	Only 7 ft/s/s w/200 lb P.F.
11C	Stop from 30 mph with WOT	DR		---			
	and P.F. from 11A	REV		---			
12	Electro-Static-Discharge		N/A	N/A	N/A	N/A	Not done for this car.

Notes: C/C = cruise control; WOT = wide open throttle; P.F. = brake pedal force

Abbreviated Summary of Data for the 1982 Toyota Cressida Test Vehicle

Series	Description of Test		Avg. Time to Target (sec)	Average Stopping Distance (ft)	Average Total Distance (ft)	Brake Pedal Force (lb)	Remarks
1	WOT to 30 mph		3.9	N/A	98	N/A	
2	Normal Idle to 100 ft		15.5		5.5 mph @ 100'		
3A	Worst case C/C to 30 mph		7.1		186		
3B	C/C speed fault to 30 mph	Low	12.2		378		105 HZ
	with low/high freq. input	High	13.3		413		140 HZ
4	WOT until stopped		Longest	32	54	Lowest	
5	WOT until brake applied		braking	17	47	P.F.	
6	Worst case C/C until stopped		delay of	15	29	of	
7	C/C speed fault (low freq. input)		2 seconds	32	55	60 lb	105 HZ
8	Min. P.F. to prevent motion						
	for worst case C/C		N/A	N/A	N/A	17	
				Minimum			
9	Min. stop from 30 mph in	DR	N/A		N/A		No Series 9 - 11c tests for Cressida
	Drive (DR) and Reverse (REV)	REV					
10	Min. stop from 30 mph	DR					
	with WOT until stopped	REV					
				Average			
11A	10.7 ft/s/s decel stop	DR	N/A		N/A		
	from 30 mph	REV					
11B	10.7 ft/s/s from 30 mph	DR					
	with WOT until stopped	REV					
11C	Stop from 30 mph with WOT	DR					
	and P.F. from 11A	REV					
12	Electro-Static-Discharge		N/A	N/A	N/A	N/A	No effect

Notes: C/C = cruise control; WOT = wide open throttle; P.F. = brake pedal force

Abbreviated Summary of Data for the 1986 Buick Electra Test Vehicle

Series	Description of Test	Avg. Time to Target (sec)	Average Stopping Distance (ft)	Average Total Distance (ft)	Brake Pedal Force (lb)	Remarks
		3.9				
1	WOT to 30 mph	20.8	N/A	96	N/A	
2	Normal Idle to 100 ft	4.0	4.6 mph @ 100'			
3A	Worst case C/C to 30 mph	5.6		100		
3B	C/C speed fault to 30 mph Low	8.4		155		36 HZ
	with low/high freq. input High			228		60 HZ
4	WOT until stopped	Longest	21	44	Lowest	
5	WOT until brake applied	braking	16	45	P.F.	
6	Worst case C/C until stopped	delay of	12	22	of	
7	C/C speed fault (low freq. input)	2 seconds	22	58	60 lb	36 HZ
8	Min. P.F. to prevent motion					
	for worst case C/C	N/A	N/A	N/A	30	
			Minimum			
9	Min. stop from 30 mph in DR	N/A		N/A		No Series 9 - 11c tests for Electra
	Drive (DR) and Reverse (REV) REV					
10	Min. stop from 30 mph DR					
	with WOT until stopped REV					
			Average			
11A	10.7 ft/s/s decel stop DR	N/A		N/A		
	from 30 mph REV					
11B	10.7 ft/s/s from 30 mph DR					
	with WOT until stopped REV					
11C	Stop from 30 mph with WOT DR					
	and P.F. from 11A REV					
12	Electro-Static-Discharge	N/A	N/A	N/A	N/A	No effect

Notes: C/C = cruise control; WOT = wide open throttle; P.F. = brake pedal force

E-41

Abbreviated Summary of Data for the 1984 Chevrolet Camaro Z28 Test Vehicle

Series	Description of Test	Avg. Time to Target (sec)	Average Stopping Distance (ft)	Average Total Distance (ft)	Brake Pedal Force (lb)	Remarks
1	WOT to 30 mph	3.4	N/A	88	N/A	
2	Normal Idle to 100 ft	16.3	4.7 mph @ 100'			
3A	Worst case C/C to 30 mph	4.4		97		
3B	C/C speed fault to 30 mph Low	4.6		134		30 HZ
	with low/high freq. input High	4.9		139		40 HZ
4	WOT until stopped	Longest	80	116	Lowest	
5	WOT until brake applied	braking	20	53	P.F.	
6	Worst case C/C until stopped	delay of	37	78	of	
7	C/C speed fault (low freq. input)	2 seconds	33	74	60 lb	30 HZ
8	Min. P.F. to prevent motion					
	for worst case C/C	N/A	N/A	N/A	26	
			Minimum			
9	Min. stop from 30 mph in DR	N/A	43	N/A	90	
	Drive (DR) and Reverse (REV) REV		50		120	
10	Min. stop from 30 mph DR		81		180	
	with WOT until stopped REV		239		78	Higher P.F. causes car to spin out
			Average			
11A	10.7 ft/s/s decel stop DR	N/A	93	N/A	18	
	from 30 mph REV		97		18	
11B	10.7 ft/s/s from 30 mph DR		119		137	
	with WOT until stopped REV		388		156	
11C	Stop from 30 mph with WOT DR		544+		19	Car wouldn't stop-steady 15 mph
	and P.F. from 11A REV		333+		25	Car wouldn't stop-increased over 35 mph
12	Electro-Static-Discharge	N/A	N/A	N/A	N/A	No effect

Notes: C/C = cruise control; WOT = wide open throttle; P.F. = brake pedal force

Abbreviated Summary of Data for the 1985 Chrysler New Yorker Test Vehicle

Series	Description of Test		Avg. Time to Target (sec)	Average Stopping Distance (ft)	Average Total Distance (ft)	Brake Pedal Force (lb)	Remarks
1	WOT to 30 mph		4.0	N/A	90	N/A	
2	Normal Idle to 100 ft		11.4		9.2 mph @ 100'		
3A	Worst case C/C to 30 mph		8.9		231		
3B	C/C speed fault to 30 mph with low/high freq. input	Low High	N/A	---	---	---	Mechanical System for New Yorker
4	WOT until stopped		Longest braking delay of 2 seconds	38	60	Lowest P.F. of 60 lb	
5	WOT until brake applied			14	38		
6	Worst case C/C until stopped			4	--		Vac. Servo Bleed Ports Plugged
7	C/C speed fault (low freq. input)			N/A	--		
8	Min. P.F. to prevent motion for worst case C/C		N/A	N/A	N/A	10	
				Minimum			
9	Min. stop from 30 mph in Drive (DR) and Reverse (REV)	DR REV	N/A		N/A		No Series 9-12 tests for New Yorker
10	Min. stop from 30 mph with WOT until stopped	DR REV					
				Average			
11A	10.7 ft/s/s decel stop from 30 mph	DR REV	N/A		N/A		
11B	10.7 ft/s/s from 30 mph with WOT until stopped	DR REV					
11C	Stop from 30 mph with WOT and P.F. from 11A	DR REV					
12	Electro-Static-Discharge		N/A	N/A	N/A	N/A	Not done for this car

Notes: C/C = cruise control; WOT = wide open throttle; P.F. = brake pedal force

Abbreviated Summary of Data for the 1985 Nissan 300ZX Test Vehicle

Series	Description of Test		Avg. Time to Target (sec)	Average Stopping Distance (ft)	Average Total Distance (ft)	Brake Pedal Force (lb)	Remarks
1	WOT to 30 mph		4.1	N/A	99	N/A	
2	Normal Idle to 100 ft		15.6		5.8 mph @ 100'		
3A	Worst case C/C to 30 mph		5.0		125		
3B	C/C speed fault to 30 mph	Low	7.1		179		40 HZ
	with low/high freq. input	High	7.3		183		42 HZ
4	WOT until stopped		Longest	36	65	Lowest	
5	WOT until brake applied		braking	14	42	P.F.	
6	Worst case C/C until stopped		delay of	30	46	of	Front Wheel Lockup
7	C/C speed fault (low freq. input)		2 seconds	7	27	60 lb	40 HZ
8	Min. P.F. to prevent motion						
	for worst case C/C		N/A	N/A	N/A	24	
				Minimum			
9	Min. stop from 30 mph in	DR	N/A		N/A		No series 9-11c tests 300ZX
	Drive (DR) and Reverse (REV)	REV					
10	Min. stop from 30 mph	DR					
	with WOT until stopped	REV					
				Average			
11A	10.7 ft/s/s decel stop	DR	N/A		N/A		
	from 30 mph	REV					
11B	10.7 ft/s/s from 30 mph	DR					
	with WOT until stopped	REV					
11C	Stop from 30 mph with WOT	DR					
	and P.F. from 11A	REV					
12	Electro-Static-Discharge		N/A	N/A	N/A	N/A	No effect

Notes: C/C = cruise control; WOT = wide open throttle; P.F. = brake pedal force

Abbreviated Summary of Data for the 1985 Cadillac DeVille Test Vehicle

Series	Description of Test		Avg. Time to Target (sec)	Average Stopping Distance (ft)	Average Total Distance (ft)	Brake Pedal Force (lb)	Remarks
1	WOT to 30 mph		4.1	N/A	105	N/A	
2	Normal Idle to 100 ft		23.3	3.6 mph @ 100'			
3A	Worst case C/C to 30 mph		4.1		106		
3B	C/C speed fault to 30 mph with low/high freq. input	Low High	N/A		---	---	Couldn't simulate failed circuit
4	WOT until stopped		Longest braking delay of 2 seconds	32	61	Lowest P.F. of 60 lb	
5	WOT until brake applied			20	56		
6	Worst case C/C until stopped			23	41		
7	C/C speed fault (low freq. input)			N/A	--		
8	Min. P.F. to prevent motion for worst case C/C		N/A	N/A	N/A	26	
9	Min. stop from 30 mph in Drive (DR) and Reverse (REV)	DR REV	N/A	Minimum	N/A		No series 9-11c tests for DeVille
10	Min. stop from 30 mph with WOT until stopped	DR REV					
11A	10.7 ft/s/s decel stop from 30 mph	DR REV	N/A	Average	N/A		
11B	10.7 ft/s/s from 30 mph with WOT until stopped	DR REV					
11C	Stop from 30 mph with WOT and P.F. from 11A	DR REV					
12	Electro-Static-Discharge		N/A	N/A	N/A	N/A	Slight increase in engine speed because of ISC motor reaction

Notes: C/C = cruise control; WOT = wide open throttle; P.F. = brake pedal force

VEHICLE RESEARCH & TEST CENTER

TEST VEHICLE RECORD

A. DESCRIPTION (TRC 76-0049)

TEST NO: 78-0128 Date 14 Oct. 88 Model Year: 84

VIN: 1MEB95F6EZ612727 Make: Mercury Model: Marquis

Color: Silver Mfg. Date: 10/83 Odometer Reading: 56,104.

✓ Auto Trans.
✓ Pwr. Brakes
✓ Pwr. Steering

✓ Auto Speed Control
☐ Anti-Lock Brakes
✓ Air Cond.
☐ Other:

Brakes:	Front	Rear
Drum		✓
Disk	✓	

Tire Size: P205/75R15 GVWR 5300

Cylinders: 8 GAWR(F) 2702

Total Displ.: 302 GAWR(R) 2668

FUEL INJECTION: ✓ Wheelbase 114.3"

CARBURETOR:

B. CONDITION AS RECEIVED

Vehicle History: VRTC test car.

Condition:

C. COMMENTS:

12-17-8

TEST PROCEDURE FOR TSC TESTS VEHICLE: 84 Mercury

Chart recorder for speed, acceleration, rpm, brake pedal force, cruise control (c/c) vacuum, throttle position, and event versus time at 10 mm/sec. Engine at normal operating temperature for all tests.

Series 1 - C/C off; Gas pedal floored after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

Run Number	1	2	3
Time to 30 mph (sec)	3.7	3.7	3.7
Total Distance Traveled	94.9	95.5	95.6

Series 2 - C/C off; Normal idle induced creep after shifting to Drive. Go to 100 ft. Repeat twice for a total of 3 runs.

Run Number	4	5	6
Time to 100 ft	14.0	14.1	13.9
Final Speed	6.0	6.6	6.6

Series 3 - C/C malfunctions after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

A) Direct short to ground of c/c vacuum pump and dump valve.

Run Number	7	8	9
Time to 30 mph (sec)	5.3	5.6	5.6
Total Distance Traveled	123.7	124.6	122.4

B) Minimum speed circuit fault (Actuate Resume in Drive with a 65 mph signal). (Frequency @ 105) ~105

Run Number	10	11	12
Time to 30 mph (sec)	15.0	15.5	13.2
Total Distance Traveled	356.8	410.5	335.3

Repeat B) with 130 mph signal. (Frequency @ 210) ~210

Run Number	13	14	15
Time to 30 mph (sec)	5.9	6.1	5.9
Total Distance Traveled	145.8	154.6	146.8

84 Mercury

Series 4 - C/C off; Gas pedal floored after shifting to Drive and until vehicle stops. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	16	17	18
Time to Stop (sec)	3.0	2.8	3.3
Speed at Brake Applied	17.2	14.7	16.2
Distance after Applied	45.7	40.8	43.2
Total Distance Traveled	74.2	63.8	67.6

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	19	20	21
Time to Stop (sec)	3.2	2.9	3.6
Speed at Brake Applied	17.2	15.2	17.7
Distance after Applied	45.2	39.4	50.7
Total Distance Traveled	74.9	61.6	80.1

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	22	23	24
Time to Stop (sec)	1.9	1.9	1.7
Speed at Brake Applied	8.2	7.2	5.4
Distance after Applied	20.1	17.6	14.4
Total Distance Traveled	27.9	22.8	19.0

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	25	26	27
Time to Stop (sec)	1.8	2.3	2.3
Speed at Brake Applied	7.2	8.0	8.5
Distance after Applied	19.0	21.2	23.8
Total Distance Traveled	25.3	27.3	31.6

84 Mercury

Series 5 - C/C off; Gas pedal floored after shifting to Drive but release throttle when brakes are applied at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	28	29	30
Time to Stop (sec)	1.2	1.0	1.0
Speed at Brake Applied	18.5	17.3	17.0
Distance after Applied	19.5	17.5	16.1
Total Distance Traveled	55.5	51.0	45.8

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	31	32	33
Time to Stop (sec)	1.3	1.1	1.0
Speed at Brake Applied	18.6	18.6	17.4
Distance after Applied	18.5	17.3	16.9
Total Distance Traveled	52.4	52.0	48.4

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	34	35	36
Time to Stop (sec)	0.9	0.8	0.7
Speed at Brake Applied	12.4	9.7	9.8
Distance after Applied	12.1	8.3	7.5
Total Distance Traveled	28.6	18.3	17.4

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	38	37	39
Time to Stop (sec)	0.8	0.6	0.8
Speed at Brake Applied	9.3	7.5	8.9
Distance after Applied	8.3	6.7	8.1
Total Distance Traveled	18.4	14.7	18.1

No mistake on
test numbers.

84 Mercury

Series 6 - C/C malfunction (Direct short to ground of c/c vacuum pump and dump valve) after shifting to Drive. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	40	41	42
Time to Stop (sec)	1.4	1.4	1.4
Speed at Brake Applied	10.5	10.3	10.8
Distance after Applied	17.0	18.5	17.3
Total Distance Traveled	28.8	31.5	30.2

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	43	44	45
Time to Stop (sec)	1.4	1.4	1.3
Speed at Brake Applied	10.9	10.6	10.6
Distance after Applied	18.4	16.8	14.9
Total Distance Traveled	32.5	29.7	27.6

		(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
49	Run Number	46	48	47
0.7	Time to Stop (sec)	1.2	0.8	0.7
0.7	Speed at Brake Applied	7.5	3.3	2.8
4.3	Distance after Applied	12.9	5.5	4.8
5.0	Total Distance Traveled	20.7	7.2	6.3

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	50	51	52
Time to Stop (sec)	0.7	0.7	0.6
Speed at Brake Applied	0.3	3.3	1.4
Distance after Applied	3.4	5.0	3.3
Total Distance Traveled	3.9	6.9	4.5

84 Mercury

Series 7 - C/C malfunction (Minimum speed circuit fault). Actuate Resume in Drive with a 65 mph signal. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each. 105 ~

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	53A	54A	55A
Time to Stop (sec)	0.8	0.8	0.9
Speed at Brake Applied	7.3	8.0	7.4
Distance after Applied	8.9	8.5	8.3
Total Distance Traveled	19.5	18.4	19.1

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	56A	57A	58A
Time to Stop (sec)	0.8	0.9	0.8
Speed at Brake Applied	7.6	8.4	8.3
Distance after Applied	8.6	7.7	7.8
Total Distance Traveled	19.0	19.9	18.8

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	59	60	61
Time to Stop (sec)	0.6	0.4	0.5
Speed at Brake Applied	2.2	1.4	1.6
Distance after Applied	3.0	1.9	2.2
Total Distance Traveled	5.3	3.3	3.8

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	63	62	64
Time to Stop (sec)	0.4	0.4	0.4
Speed at Brake Applied	1.8	1.4	1.4
Distance after Applied	1.4	1.4	1.3
Total Distance Traveled	2.5	2.9	2.5

Note: Runs 65 through 77 were not 150 lb. pedal force minimum stops.

84 Mercury

Series 8 - C/C malfunction - direct short to ground of c/c vacuum pump but dump valve vacuum plugged. Determine minimum brake pedal force to prevent vehicle movement after shifting to Drive. Apply brakes in Park and maintain that level after shifting to Drive.

Brake Pedal Force	*24-28	*24-28			
Stopped in Drive	Yes	Yes			

* Forward motion is stopped, but rear tires still spin.

Series 9 - Measure minimum stopping distance from 30 mph (wheel lockup OK).

In Drive:

Run Number	78	79	
Time to Stop (sec)	1.8	1.9	
Speed at Brake Applied	30.2	30.4	
Distance after Applied	43.6	42.8	
Pedal Force	156.	144.	

In Reverse:

Run Number	80	81	
Time to Stop (sec)	2.1	2.1	
Speed at Brake Applied	30.0	30.1	
Distance after Applied	49.9	49.0	
Pedal Force	150.	150.	

84 Mercury

. Series 10 - Repeat Series 9 but hold throttle wide open.

In Drive:

Run Number	82	83	84
Time to Stop (sec)	5.4	5.7	5.4
Speed at Brake Applied	32.5	32.2	32.5
Distance after Applied	116.4	119.2	116.1
Pedal Force	144.	150.	154.

In Reverse:

Run Number	85	86	87
Time to Stop (sec)	5.2	5.3	5.9
Speed at Brake Applied	31.6	31.8	32.3
Distance after Applied	117.2	117.7	132.2
Pedal Force	175.	144.	152.

Series 11 - A) Measure stopping distance and pedal force from 30 mph for a 10.7 ft/sec/sec deceleration.

In Drive:

Run Number	88	89	90
Time to Stop (sec)	4.0	3.9	4.0
Speed at Brake Applied	30.5	29.9	30.1
Distance after Applied	97.3	94.8	96.4
Pedal Force	16.	16.	16.

In Reverse:

95	96	Run Number	91	92	93	94
4.3	4.1	Time to Stop (sec)	4.3	4.9	5.3	4.
29.9	29.7	Speed at Brake Applied	29.0	29.7	30.1	29.
101.7	94.8	Distance after Applied	94.1	108.1	119.4	90.
12.	12.	Pedal Force	12.	12.	10.	14.

84 Mercury

Series 11 - B) Measure pedal force for a 30 mph with a 10.7 ft/sec/sec deceleration (same stopping distance as A) but hold the throttle wide open.

In Drive:

Run Number	97	98	99
Time to Stop (sec)	5.9	7.2	5.9
Speed at Brake Applied	32.5	32.2	32.7
Distance after Applied	134.8	145.4	130.4
Pedal Force	108.	102.	130.

In Reverse:

Run Number	100		
Time to Stop (sec)	6.8		
Speed at Brake Applied	32.7		
Distance after Applied	160.3		
Pedal Force	128.		

Series 11 - C) Measure stopping distance from 30 mph with the throttle held wide open but the same pedal force as measured in Series 11 - A).

In Drive:

Run Number	101		
Time to Stop (sec)	19.4		
Speed at Brake Applied	32.3		
Distance after Applied	415.5	before aborting run.	
Pedal Force	20		

In Reverse:

Run Number			
Time to Stop (sec)			
Speed at Brake Applied			
Distance after Applied			
Pedal Force			

Series 12 - Electro-Static Discharge Tests - Identify which piece of wiring harness goes to the cruise control. Point-and-Shoot procedure to be used.

No Effect.

VEHICLE RESEARCH & TEST CENTER

TEST VEHICLE RECORD

A. DESCRIPTION (TRC 76-0049)

TEST NO: 78-0128 Date 10-19-88 Model Year: 1988

VIN: WDB(EA30)D3JA579664 Make: Mercedes Model: 300E

Color: burgundy Mfg. Date: 9/87 Odometer Reading: 18,624.

✓ Auto Trans.
✓ Pwr. Brakes
✓ Pwr. Steering

✓ Auto Speed Control
✓ Anti-Lock Brakes
✓ Air Cond.
Other:

Brakes:	Front	Rear
Drum		
Disk	✓	✓

Tire Size: 195/65VR15 GVWR 4255

Cylinders: 6 GAWR(F) 2000

Total Displ.: 180.8 3.0L GAWR(R) 2255

FUEL INJECTION: ✓ Wheelbase 110.2"

CARBURETOR: F.I.

B. CONDITION AS RECEIVED

Vehicle History:

Condition:

C. COMMENTS:

12-17-8

TEST PROCEDURE FOR TSC TESTS VEHICLE: 300E

Chart recorder for speed, acceleration, rpm, brake pedal force, cruise control (c/c) vacuum, throttle position, and event versus time at 10 mm/sec. Engine at normal operating temperature for all tests.

Series 1 - C/C off; Gas pedal floored after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

Run Number	1	2	3
Time to 30 mph (sec)	4.1	3.8	3.9
Total Distance Traveled	100.4	93.4	97.4

Series 2 - C/C off; Normal idle induced creep after shifting to Drive. Go to 100 ft. Repeat twice for a total of 3 runs.

Run Number	4	5	6
Time to 100 ft	18.2	16.6	15.4
Final Speed	5.2	5.9	6.1

Series 3 - C/C malfunctions after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

A) Direct short to ground of c/c vacuum pump and dump valve.

Run Number	7	8	9
Time to 30 mph (sec)	10.8	9.0	10.2
Total Distance Traveled	317.4	264.6	294.5

B) Minimum speed circuit fault (Actuate Resume in Drive with a ~~65~~ 60 mph signal). (Frequency @ 120) ~~105~~

10	11	12	Run Number	13	14	15	1
12.9	6.0	6.8	Time to 30 mph (sec)	20.3	9.8	8.7	9.7
349.8	141.9	158.1	Total Distance Traveled	547.3	263.0	218.3	249

Repeat B) with ~~130~~ 120 mph signal. (Frequency @ 240) ~210

Run Number	17	18	19
Time to 30 mph (sec)	8.7	6.1	6.8
Total Distance Traveled	222.0	140.4	154.1

300E

Series 4 - C/C off; Gas pedal floored after shifting to Drive and <u>until vehicle stops</u>. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	21	22	20
Time to Stop (sec)	5.8	4.6	6.9
Speed at Brake Applied	12.5	13.7	14.9
Distance after Applied	51.0	46.1	60.6
Total Distance Traveled	69.4	69.8	84.4

2sec/100 lb.			(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
24	25	Run Number	23	26	27
5.2	4.8	Time to Stop (sec)	4.1	3.9	3.8
14.2	14.3	Speed at Brake Applied	13.8	13.8	13.5
48.6	46.5	Distance after Applied	42.5	41.9	36.5
71.1	70.7	Total Distance Traveled	65.0	65.4	57.3

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	28	29	30
Time to Stop (sec)	3.8	4.3	4.1
Speed at Brake Applied	7.4	6.8	5.8
Distance after Applied	24.8	26.0	26.8
Total Distance Traveled	30.4	30.2	31.2

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	31	32	33
Time to Stop (sec)	4.0	2.9	2.7
Speed at Brake Applied	7.3	6.2	7.8
Distance after Applied	25.0	17.7	18.0
Total Distance Traveled	29.7	22.2	24.1

300 E

Series 5 - C/C off; Gas pedal floored after shifting to Drive but release throttle when brakes are applied at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	34	35	36
Time to Stop (sec)	1.0	1.0	1.0
Speed at Brake Applied	15.5	15.3	16.0
Distance after Applied	14.0	14.6	15.0
Total Distance Traveled	40.5	43.2	43.3

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	37	38	39
Time to Stop (sec)	1.0	1.0	1.0
Speed at Brake Applied	15.1	16.6	15.7
Distance after Applied	14.8	14.7	14.4
Total Distance Traveled	44.2	44.0	43.9

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	42	43	40
Time to Stop (sec)	0.6	0.6	0.7
Speed at Brake Applied	8.5	9.0	7.6
Distance after Applied	6.2	6.4	6.1
Total Distance Traveled	15.1	14.7	14.1

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	41	44	45
Time to Stop (sec)	0.7	0.8	0.7
Speed at Brake Applied	9.5	10.0	8.0
Distance after Applied	7.0	7.4	6.4
Total Distance Traveled	16.7	17.6	14.3

Series 6 - C/C malfunction (Direct short to ground of c/c vacuum pump and dump valve) after shifting to Drive. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	46	47	48
Time to Stop (sec)	0.8	0.8	0.8
Speed at Brake Applied	9.3	10.2	9.3
Distance after Applied	9.2	9.5	9.1
Total Distance Traveled	21.6	23.7	22.2

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	49	50	51
Time to Stop (sec)	0.8	0.8	0.9
Speed at Brake Applied	8.4	10.4	10.8
Distance after Applied	8.9	9.9	10.5
Total Distance Traveled	22.3	24.5	25.8

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	52	53	54
Time to Stop (sec)	0.6	0.5	0.6
Speed at Brake Applied	2.4	3.1	4.4
Distance after Applied	3.4	2.5	3.7
Total Distance Traveled	5.4	4.1	6.7

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	55	56	57
Time to Stop (sec)	0.7	0.5	0.6
Speed at Brake Applied	4.0	3.7	4.2
Distance after Applied	3.9	2.8	3.6
Total Distance Traveled	5.9	4.7	6.0

300 E

Series 7 - C/C malfunction (Minimum speed circuit fault). Actuate Resume in Drive with a 65 mph signal. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each. (120~)

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	59	60	58
Time to Stop (sec)	0.6	0.6	0.4
Speed at Brake Applied	5.2	6.1	4.8
Distance after Applied	3.6	4.6	2.6
Total Distance Traveled	10.0	11.9	

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	61	62	63
Time to Stop (sec)	0.7	0.5	0.5
Speed at Brake Applied	6.3	5.2	4.3
Distance after Applied	5.0	3.3	2.7
Total Distance Traveled	12.7	9.7	8.7

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	64	65	66
Time to Stop (sec)	0.3	0.4	0.3
Speed at Brake Applied	1.1	1.0	1.4
Distance after Applied	1.3	1.5	1.0
Total Distance Traveled			

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	67	68	69
Time to Stop (sec)	0.3	0.3	0.3
Speed at Brake Applied	1.0	1.2	1.2
Distance after Applied	1.2	1.2	1.1
Total Distance Traveled	1.9	1.9	1.9

300E

Series 8 - C/C malfunction - direct short to ground of c/c vacuum pump but dump valve vacuum plugged. Determine minimum brake pedal force to prevent vehicle movement after shifting to Drive. Apply brakes in Park and maintain that level after shifting to Drive.

Brake Pedal Force	35	40			
Stopped in Drive	no	yes			

Once the car starts to move, it takes 70-80 lbs. of P.F. to stop it.

Series 9 - Measure minimum stopping distance from 30 mph (wheel lockup OK).

In Drive:

Run Number	70	71	72
Time to Stop (sec)	1.9	1.8	1.7
Speed at Brake Applied	30.5	30.7	30.2
Distance after Applied	49.4	45.1	41.6
Pedal Force	70.	70.	60.-70.

In Reverse:

Run Number	73	74	75	76
Time to Stop (sec)	2.5	2.5	2.8	2.4
Speed at Brake Applied	29.7	29.9	30.0	29.9
Distance after Applied	54.6	55.7	64.3	52.9
Pedal Force	70.	70.	40.-60.	70.

300 E

Series 10 - Repeat Series 9 but hold throttle wide open.

In Drive:

Run Number	77	78	79	80
Time to Stop (sec)	6.3	6.3	5.2	5.9
Speed at Brake Applied	33.0	34.9	33.8	35.1
Distance after Applied	160.7	171.0	139.5	163.6
Pedal Force	150.-160.	150.-160.	150.-160.	150.

In Reverse:

Run Number	81	82	83
Time to Stop (sec)	9.1	10.5	9.5
Speed at Brake Applied	29.8	29.7	30.2
Distance after Applied	176.8	204.8	173.4
Pedal Force	190.-200.	160.-170.	160.-170.

Series 11 - A) Measure stopping distance and pedal force from 30 mph for a 10.7 ft/sec/sec deceleration.

In Drive:

Run Number	84	85	86	87
Time to Stop (sec)	3.7	4.6	4.0	4.4
Speed at Brake Applied	30.4	30.4	29.9	30.7
Distance after Applied	85.2	109.3	95.3	107.4
Pedal Force	12.-16.	12.-20.	12.-20.	18.

In Reverse:

Run Number	88	89	90
Time to Stop (sec)	4.3	4.0	4.0
Speed at Brake Applied	29.6	29.4	28.6
Distance after Applied	92.7	84.1	82.8
Pedal Force	16.-18.	18.-20.	10.-20.

300 E

Series 11 - B) Measure pedal force for a 30 mph with a 10.7 ft/sec/sec deceleration (same stopping distance as A) but hold the throttle wide open.

In Drive:

Run Number	91	92	93
Time to Stop (sec)	5.9	5.7	5.4
Speed at Brake Applied	33.3	32.6	33.5
Distance after Applied	161.6	145.0	138.8
Pedal Force	120.	130.	140.

In Reverse:

Run Number	94	95	96
Time to Stop (sec)	15.5	10.9	8.3
Speed at Brake Applied	29.9	30.0	30.2
Distance after Applied	273.	193.3	151.7
Pedal Force	100.	160.	200.
Decel (ft. sec^2)	5.	6.	7.

Series 11 - C) Measure stopping distance from 30 mph with the throttle held wide open but the same pedal force as measured in Series 11 - A).

In Drive:

Run Number			
Time to Stop (sec)			
Speed at Brake Applied			
Distance after Applied			
Pedal Force			

In Reverse:

Run Number			
Time to Stop (sec)			
Speed at Brake Applied			
Distance after Applied			
Pedal Force			

Series 12 - Electro-Static Discharge Tests - Identify which piece of wiring harness goes to the cruise control. Point-and-Shoot procedure to be used.

Not done for this car.

VEHICLE RESEARCH & TEST CENTER

TEST VEHICLE RECORD

A. DESCRIPTION (~~[illegible]~~)

TEST NO: 78-0128 Date 11/02/88 Model Year: 82

VIN: JT2MX62E0C0035028 Make: Toyota Model: Cressida

Color: White Mfg. Date: 10/81 Odometer Reading: 20,332

✓ Auto Trans.
✓ Pwr. Brakes
✓ Pwr. Steering

✓ Auto Speed Control
Anti-Lock Brakes
✓ Air Cond.
Other:

Brakes:	Front	Rear
Drum		✓
Disc	✓	

Tire Size: 185/70R14 GVWR 3825

Cylinders: 6 GAWR(F) 2095

Total Displ.: 2.8L GAWR(R) 2140

FUEL INJECTION: ✓ Wheelbase 104"

CARBURETOR:

B. CONDITION AS RECEIVED

Vehicle History:

Condition:

C. COMMENTS:

12-17-

TEST PROCEDURE FOR TSC TESTS VEHICLE: Toyota

Chart recorder for speed, acceleration, rpm, brake pedal force, cruise control (c/c) vacuum, throttle position, and event versus time at 10 mm/sec. Engine at normal operating temperature for all tests.

Series 1 - C/C off; Gas pedal floored after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

Run Number	1	2	3
Time to 30 mph (sec)	3.8	4.0	3.9
Total Distance Traveled	95.9	99.3	97.5

Series 2 - C/C off; Normal idle induced creep after shifting to Drive. Go to 100 ft. Repeat twice for a total of 3 runs.

Run Number	4	5	6	7
Time to 100 ft	16.3	15.2	15.4	15.1
Final Speed	5.1	5.6	5.6	5.6

Series 3 - C/C malfunctions after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

A) Direct short to ground of c/c vacuum pump and dump valve.

Run Number	8	9	10
Time to 30 mph (sec)	7.2	7.0	7.2
Total Distance Traveled	189.8	180.5	187.4

B) Minimum speed circuit fault (Actuate Resume in Drive with a 65 mph signal). (Frequency @ 105) ~105

Run Number	11	12	13
Time to 30 mph (sec)	12.2	11.3	13.0
Total Distance Traveled	380.6	358.0	396.9

Repeat B) with 130 mph signal. (Frequency @ 140) ~210

Run Number	14	15	16
Time to 30 mph (sec)	13.7	16.2	9.9
Total Distance Traveled	428.2	514.1	295.3

Toyota

Series 4 - C/C off; Gas pedal floored after shifting to Drive and until vehicle stops. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	17	18	19
Time to Stop (sec)	2.4	2.5	2.1
Speed at Brake Applied	14.2	13.8	13.9
Distance after Applied	30.9	32.6	26.4
Total Distance Traveled	52.6	54.9	47.6

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	20	21	22
Time to Stop (sec)	2.2	2.0	2.0
Speed at Brake Applied	14.8	16.3	14.1
Distance after Applied	27.7	28.2	26.7
Total Distance Traveled	52.4	57.0	49.6

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	23	24	25
Time to Stop (sec)	1.6	1.6	1.6
Speed at Brake Applied	7.1	7.3	9.7
Distance after Applied	14.0	13.2	16.4
Total Distance Traveled	19.8	18.7	26.0

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	26	27	28
Time to Stop (sec)	1.3	1.2	1.2
Speed at Brake Applied	6.8	7.2	6.5
Distance after Applied	10.5	11.0	10.6
Total Distance Traveled	15.7	17.5	16.6

Toyota

29

Series 5 - C/C off; Gas pedal floored after shifting to Drive but release throttle when brakes are applied at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

* verified 17.2 each

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	29	30	31
Time to Stop (sec)	1.1	1.0	1.0
Speed at Brake Applied	17.2 *	16.6	15.9
Distance after Applied	17.2	15.9	14.2
Total Distance Traveled	47.2	46.4	40.5

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	32	33	34
Time to Stop (sec)	1.1	1.0	1.0
Speed at Brake Applied	17.5	16.8	16.9
Distance after Applied	17.1	15.4	15.4
Total Distance Traveled	51.3	45.5	45.5

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	37	38	35
Time to Stop (sec)	0.8	0.8	0.8
Speed at Brake Applied	10.2	9.1	10.6
Distance after Applied	7.7	7.7	7.7
Total Distance Traveled	16.8	17.8	18.1

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	36	39	40
Time to Stop (sec)	0.8	0.6	0.8
Speed at Brake Applied	9.5	10.3	12.1
Distance after Applied	7.4	6.6	9.3
Total Distance Traveled	17.1	16.3	22.9

Toyota

Series 6 - C/C malfunction (Direct short to ground of c/c vacuum pump and dump valve) after shifting to Drive. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	41	42	43
Time to Stop (sec)	1.6	1.5	1.2
Speed at Brake Applied	9.9	9.7	9.2
Distance after Applied	15.8	14.8	12.2
Total Distance Traveled	29.4	28.4	25.5

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	44	45	46
Time to Stop (sec)	1.2	1.1	1.0
Speed at Brake Applied	9.5	10.6	9.0
Distance after Applied	12.1	11.7	9.1
Total Distance Traveled	24.8	26.4	21.0

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	47	48	49
Time to Stop (sec)	0.9	0.9	0.6
Speed at Brake Applied	3.7	4.6	2.9
Distance after Applied	5.4	5.2	3.3
Total Distance Traveled	8.2	7.9	5.1

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	50	51	52
Time to Stop (sec)	0.5	0.5	0.5
Speed at Brake Applied	2.0	2.0	2.8
Distance after Applied	2.6	2.7	2.6
Total Distance Traveled	4.0	4.4	4.5

Toyota

Series 7 - C/C malfunction (Minimum speed circuit fault). Actuate Resume in Drive with a 65 mph signal. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each. 105 N

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	55	56	57
Time to Stop (sec)	2.8	2.8	2.1
Speed at Brake Applied	13.1	12.0	11.7
Distance after Applied	32.5	30.9	23.6
Total Distance Traveled	59.0	51.1	45.8

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	58	59	60
Time to Stop (sec)	1.9	1.4	1.5
Speed at Brake Applied	12.6	11.9	11.7
Distance after Applied	22.3	17.0	17.5
Total Distance Traveled	48.2	37.5	37.5

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	61	62	63
Time to Stop (sec)	1.2	1.5	1.0
Speed at Brake Applied	5.9	5.4	5.4
Distance after Applied	8.3	9.7	7.1
Total Distance Traveled	14.0	15.2	12.7

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)	
Run Number	64	65	66	67
Time to Stop (sec)	1.0	0.8	0.8	0.8
Speed at Brake Applied	6.5	6.3	5.7	6.1
Distance after Applied	7.8	5.6	5.9	5.6
Total Distance Traveled	13.8	11.8	~~04~~	11.5

Toyota

Series 8 - C/C malfunction - direct short to ground of c/c (worst case) ~~vacuum pump but dump valve vacuum plugged~~. Determine minimum brake pedal force to prevent vehicle movement after shifting to Drive. Apply brakes in Park and maintain that level after shifting to Drive.

Brake Pedal Force	18	10	15	16	17
Stopped in Drive	yes	no	no	no	yes

Conversion Reference (mph x 1.6093 = km/h):

MPH	20	25	30	35	40	45	50	55	60	65	130
KM/HR	32	40	48	56	64	72	80	89	97	105	210

Note: No throttle opening during ESD tests.

VEHICLE RESEARCH & TEST CENTER

TEST VEHICLE RECORD

A. DESCRIPTION

TEST NO: 78-0128 Date 11/07/88 Model Year: 86

VIN: 1G4CX69B1G1505433 Make: Buick Model: Electra

Color: Wine Mfg. Date: 05/86 Odometer Reading: 7676

✓ Auto Trans.
✓ Pwr. Brakes
✓ Pwr. Steering

✓ Auto Speed Control
✓ Anti-Lock Brakes
✓ Air Cond.
__ Other: ____

Brakes:	Front	Rear
Drum		✓
Disk	✓	

Tire Size: P205/75R14 4374

Cylinders: 6 GAWR(F) 2366

Total Displ.: 3.8 GAWR(R) 2008

FUEL INJECTION: ✓ Wheelbase 111"

CARBURETOR: ____

B. CONDITION AS RECEIVED

Vehicle History: VRTC test vehicle.

Condition: Brake test car. Impact tests als

C. COMMENTS:

12-17

TEST PROCEDURE FOR TSC TESTS VEHICLE: Buick Electra

Chart recorder for speed, acceleration, rpm, brake pedal force, cruise control (c/c) vacuum, throttle position, and event versus time at 10 mm/sec. Engine at normal operating temperature for all tests.

Series 1 - C/C off; Gas pedal floored after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

Run Number	1	2	3
Time to 30 mph (sec)	3.9	4.0	3.8
Total Distance Traveled	94.9	98.5	93.8

Series 2 - C/C off; Normal idle induced creep after shifting to Drive. Go to 100 ft. Repeat twice for a total of 3 runs.

Run Number	4	5	6	7
Time to 100 ft	24.8	24.6	16.7	17.3
Final Speed	3.5	3.6	5.7	5.4

Series 3 - C/C malfunctions after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

A) Direct short to ground of c/c vacuum pump and dump valve.

Run Number	8	9	10
Time to 30 mph (sec)	4.1	4.0	4.0
Total Distance Traveled	101.1	97.6	99.9

B) Minimum speed circuit fault (Actuate Resume in Drive with a 65 mph signal). (Frequency @ 36) ~105

Run Number	47	48	49	50	51	52
Time to 30 mph (sec)	7.9	4.0	4.1	4.1	7.4	6.
Total Distance Traveled	229.3	97.4	102.9	98.6	217.7	181

Repeat B) with 130 mph signal. (Frequency @ 60) ~210

Run Number	52A	53	54	55	56	57
Time to 30 mph (sec)	6.9	6.7	6.6	8.3	11.9	9.8
Total Distance Traveled	177.1	169.8	175.0	227.8	346.2	272.9

Buick

Series 4 - C/C off; Gas pedal floored after shifting to Drive and until vehicle stops. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	11	12	13
Time to Stop	1.4	1.4	1.2
Speed at Brake Applied	14.7	16.2	16.1
Distance after Applied	18.6	23.8	19.5
Total Distance Traveled	39.5	49.5	44.4

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	14	15	16
Time to Stop	1.2	1.2	1.4
Speed at Brake Applied	15.8	14.0	16.2
Distance after Applied	18.2	17.4	19.5
Total Distance Traveled	43.2	39.7	45.6

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	17	18	19
Time to Stop	0.6	1.0	0.6
Speed at Brake Applied	8.1	8.4	7.0
Distance after Applied	6.4	9.7	6.5
Total Distance Traveled	12.9	16.6	12.5

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	20	21	22
Time to Stop	0.6	0.8	0.6
Speed at Brake Applied	6.5	6.3	6.3
Distance after Applied	7.1	6.4	6.3
Total Distance Traveled	12.9	11.6	11.5

} yes 6.3

Buick

Series 5 - C/C off; Gas pedal floored after shifting to Drive but <u>release throttle when brakes are applied</u> at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	23	24	25
Time to Stop	1.2	1.2	1.2
Speed at Brake Applied	16.0	17.0 } yes	16.0
Distance after Applied	14.8	17.0	16.7
Total Distance Traveled	43.2	47.7	45.4

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	26	27	28
Time to Stop	1.2	1.1	1.4
Speed at Brake Applied	16.0	15.8	17.3
Distance after Applied	16.2	14.8	20.1
Total Distance Traveled	43.1	42.0	53.9

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	29	30	31
Time to Stop	0.6	0.6	0.8
Speed at Brake Applied	9.3	9.5	9.4
Distance after Applied	6.2	6.9	6.9
Total Distance Traveled	15.7	17.9	17.2

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	32	33	34
Time to Stop	0.7	0.5	0.8
Speed at Brake Applied	8.6	8.4	8.8
Distance after Applied	6.3	5.5	7.0
Total Distance Traveled	15.4	13.1	16.1

Buick

Series 6 - C/C malfunction (Direct short to ground of c/c vacuum pump and dump valve) after shifting to Drive. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	35	36	37
Time to Stop (sec)	1.2	0.9	1.0
Speed at Brake Applied	11.5	7.3	9.3
Distance after Applied	13.7	9.9	10.9
Total Distance Traveled	27.3	17.5	22.1

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)		
Run Number	38	39	40	40A	40
Time to Stop (sec)	1.2	1.0	1.0	1.0	1.
Speed at Brake Applied	12.3	10.0	11.7	10.4	10.
Distance after Applied	15.6	11.1	11.1	12.6	10.
Total Distance Traveled	31.7	23.0	25.4	26.9	23.

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	41	42	43
Time to Stop (sec)	0.9	0.8	0.8
Speed at Brake Applied	5.9	3.5	3.4
Distance after Applied	6.1	5.0	5.0
Total Distance Traveled	10.3	7.6	7.4

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	44	45	46
Time to Stop (sec)	0.8	0.7	0.8
Speed at Brake Applied	4.2	1.9	3.5
Distance after Applied	4.6	2.8	3.9
Total Distance Traveled	7.0	4.0	5.8

1°

Buick

Series 7 - C/C malfunction (Minimum speed circuit fault). Actuate Resume in Drive with a 65 mph signal. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each. 36 N

	L.U. (lock up) (2sec/60lb)	L.U. (2sec/60lb)	L.U. (2sec/100lb)
Run Number	70	71	72
Time to Stop (sec)	1.2	1.2	1.2
Speed at Brake Applied	18.9	18.0	18.4
Distance after Applied	22.1	22.0	23.6
Total Distance Traveled	59.4	56.0	62.7

	L.U. (2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	73		
Time to Stop (sec)	1.5		
Speed at Brake Applied	17.4		
Distance after Applied	21.1		
Total Distance Traveled	52.9		

	L.U. (1sec/60lb)	L.U. (1sec/60lb)	LU (1sec/100lb)
Run Number	74	75	76
Time to Stop (sec)	1.0	1.0	1.0
Speed at Brake Applied	12.2	11.7	13.1
Distance after Applied	12.4	12.2	12.7
Total Distance Traveled	26.5	24.8	28.8

	L.U. (1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	77		
Time to Stop (sec)	0.9		
Speed at Brake Applied	10.4 } yes		
Distance after Applied	10.4		
Total Distance Traveled	22.9		

Buick.

Series 8 - C/C malfunction - direct short to ground of c/c vacuum pump but dump valve vacuum plugged. Determine minimum brake pedal force to prevent vehicle movement after shifting to Drive. Apply brakes in Park and maintain that level after shifting to Drive.

Brake Pedal Force	10	29	30	40	35	32	30		
Stopped in Drive	no	no	no	yes	yes	yes	just holds		

Electro-Static Discharge Tests - Identify which piece of wiring harness goes to the cruise control. Point-and-Shoot procedure to be used. Use 25 KV for magnetic loop and 10,000 KV for spark tip tests. Note results, especially if tests cause intermittent throttle opening.

ESD completed 11/9/88

No throttle opening.

VEHICLE RESEARCH & TEST CENTER

TEST VEHICLE RECORD

A. DESCRIPTION

TEST NO: 78-0128 Date 11/17/88 Model Year: 1984

VIN: 1G1AP876XEN117380 Make: Chevrolet Model: Camaro Z28

Color: Cream Mfg. Date: 10/83 Odometer Reading: 60,481

✓ Auto Trans. (overdrive)
✓ Pwr. Brakes
✓ Pwr. Steering

✓ Auto Speed Control
N/A Anti-Lock Brakes
✓ Air Cond.
___ Other: ______

Brakes:	Front	Rear
Drum		✓
Disk	✓	

GY Eagle GT
Tire Size: P215/65R15 GVWR 4133

Cylinders: V-8 GAWR(F) 2138

Total Displ.: 5.0L GAWR(R) 1995

FUEL INJECTION: N/A Wheelbase 101"
CARBURETOR: 4BBL quadrajet

B. CONDITION AS RECEIVED

Vehicle History: Bought "used" from Cottonwood Motor Sales on 11/3/88

Condition:

C. COMMENTS:

10-17-

TEST PROCEDURE FOR TSC TESTS VEHICLE: Camaro

Chart recorder for speed, acceleration, rpm, brake pedal force, cruise control (c/c) vacuum, throttle position, and event versus time at 10 mm/sec. Engine at normal operating temperature for all tests.

Series 1 - C/C off; Gas pedal floored after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

Run Number	1	2	3
Time to 30 mph (sec)	3.5	3.5	3.3
Total Distance Traveled	89.5	90.8	84.0

Series 2 - C/C off; Normal idle induced creep after shifting to Drive. Go to 100 ft. Repeat twice for a total of 3 runs.

Run Number	4	5	6	7
Time to 100 ft	17.4	17.2	15.1	15.4
Final Speed	4.3 uphill	4.4 u.h.	5.1 dh.	5.1 dh.

Series 3 - C/C malfunctions after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

A) Direct short to ground of c/c vacuum pump and dump valve.

Run Number	56	57	58
Time to 30 mph (sec)	4.5	4.4	4.4
Total Distance Traveled	97.8	95.6	97.4

B) Minimum speed circuit fault (Actuate Resume in Drive with a 65 mph signal). (Frequency @ 30) ~105

Run Number	59	60	61
Time to 30 mph (sec)	4.3	4.7	4.7
Total Distance Traveled	122.5	141.4	137.2

Repeat B) with 130 mph signal. (Frequency @ 40) ~210

Run Number	62	63	64
Time to 30 mph (sec)	3.6	4.8	6.4
Total Distance Traveled	95.3	139.8	182.4

Camaro

Series 4 - C/C off; Gas pedal floored after shifting to Drive and <u>until vehicle stops</u>. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)	
Run Number	8	9	10	
Time to Stop (sec)	5.0	5.2	3.2	Pedal
Speed at Brake Applied	18.7	19.8	18.0	Force
Distance after Applied	78.5	82.1	49.2	Higher
Total Distance Traveled	112.5	120.5	78.8	

	(2sec/100lb)		(2sec/150lb)	(2sec/150lb)	
Run Number	11	15	12	13	14
Time to Stop (sec)	4.1	4.6	4.1	2.7	2.8
Speed at Brake Applied	18.3	18.3	18.8	18.0	18.8
Distance after Applied	63.7	65.3	57.2	38.6	46.0
Total Distance Traveled	98.2	96.6	88.3 *	67.8	79.

* early downshift

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	16	17	19
Time to Stop (sec)	6.1	5.6	3.3
Speed at Brake Applied	10.0	8.9	8.7
Distance after Applied	80.1	67.0	37.7
Total Distance Traveled	90.4	75.4	46.6

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	20	21	22
Time to Stop (sec)	2.6	2.5	2.8
Speed at Brake Applied	8.8	9.9	10.4
Distance after Applied	27.2	24.1	30.7
Total Distance Traveled	35.7	34.2 *	40.6 *

* Front wheels locked.
Lost steering control.
∠ 45° spin.

23

Camaro

Series 5 - C/C off; Gas pedal floored after shifting to Drive but release throttle when brakes are applied at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	23	24	25
Time to Stop (sec)	1.3	1.2	1.2
Speed at Brake Applied	18.0	16.1	18.5
Distance after Applied	22.3	17.8	20.8
Total Distance Traveled	56.6	50.1	54.5

	(2sec/100lb)		(2sec/150lb)	(2sec/150lb)	
Run Number	26	27	28	29	3
Time to Stop (sec)	1.2	1.2	1.1	1.0	1.
Speed at Brake Applied	19.2	17.7	17.6	15.2	18.
Distance after Applied	22.6	20.3	18.0	15.6	20.
Total Distance Traveled	58.9	52.4	51.2	45.5	57.

|← Lock up →

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	31	32	33
Time to Stop (sec)	1.0	0.8	0.8
Speed at Brake Applied	11.9	11.2	10.7
Distance after Applied	11.2	8.7	8.8
Total Distance Traveled	24.7	20.9	20.7

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	34	35	36
Time to Stop (sec)	0.8	0.8	0.8
Speed at Brake Applied	10.8	11.9	11.5
Distance after Applied	9.5	9.5	8.6
Total Distance Traveled	20.9	21.4	21.3

Camaro

Series 6 - C/C malfunction (Direct short to ground of c/c vacuum pump and dump valve) after shifting to Drive. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each. 30N

	(2sec/601b)	(2sec/601b)	(2sec/1001b)
Run Number	79	80	81
Time to Stop (sec)	1.8	1.8	1.6
Speed at Brake Applied	19.8	19.1	20.2
Distance after Applied	37.5	36.5	32.9
Total Distance Traveled	78.8	76.4	72.8

	(2sec/1001b)	(2sec/1501b)	(2sec/1501b)
Run Number	82	83	84
Time to Stop (sec)	1.6	1.2	1.2
Speed at Brake Applied	20.6	16.8	15.9
Distance after Applied	33.1	21.7	20.9
Total Distance Traveled	74.4	50.1	48.2

	(1sec/601b)		(1sec/601b)		(1sec/1001b)
Run Number	85		86	87	88
Time to Stop (sec)	1.5	delay time too long	1.3	1.3	1.2
Speed at Brake Applied	16.9		12.9	12.1	10.8
Distance after Applied	27.6		19.3	18.8	16.2
Total Distance Traveled	58.3		34.7	33.8	29.5

	(1sec/1001b)	(1sec/1501b)	(1sec/1501b)	
Run Number	89	90	91	92
Time to Stop (sec)	1.2	1.0	1.0	1.0
Speed at Brake Applied	11.4	12.1	11.4	12.7
Distance after Applied	16.6	14.1	13.9	14.5
Total Distance Traveled	31.4	28.2	26.3	28.9

Camaro

Series 7 - C/C malfunction (Minimum speed circuit fault). Actuate Resume in Drive with a 65 mph signal. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each. 30~

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	65	66	67
Time to Stop (sec)	1.6	1.6	1.4
Speed at Brake Applied	19.8	18.8	17.9
Distance after Applied	34.0	31.5	24.4
Total Distance Traveled	76.5	71.2	77.3

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	68	69	70
Time to Stop (sec)	1.4	1.4	1.4
Speed at Brake Applied	19.0	19.5	19.2
Distance after Applied	25.1	26.6	25.2
Total Distance Traveled	64.6	66.0	63.3

|← Lock up @ end of stop|

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	71	72	73
Time to Stop (sec)	1.2	1.2	1.2
Speed at Brake Applied	11.8	11.5	13.3
Distance after Applied	17.1	17.6	17.4
Total Distance Traveled	30.4	31.7	33.1

mild lock up @ end.

	(1sec/100lb)		(1sec/150lb)	(1sec/150lb)	
Run Number	74	75	76	77	78
Time to Stop (sec)	1.2	1.2	1.0	1.1	1.2
Speed at Brake Applied	11.7	12.2	12.2	13.5	13.6
Distance after Applied	17.4	17.2	15.2	16.8	17.0
Total Distance Traveled	32.3	33.0	31.1	33.6	34.1

Camaro

Series 8 - C/C malfunction - direct short to ground of c/c vacuum pump but dump valve vacuum plugged. Determine minimum brake pedal force to prevent vehicle movement after shifting to Drive. Apply brakes in Park and maintain that level after shifting to Drive.

#93

Brake Pedal Force	20	40	25	30	27	26	2
Stopped in Drive	no	yes	no	yes	yes	yes	n

In each case, drive wheels spun with car at zero speed.

Series 9 - Measure minimum stopping distance from 30 mph (wheel lockup OK).

In Drive:

Run Number	37	38	39	40
Time to Stop (sec)	1.7	1.7	1.8	1.8
Speed at Brake Applied	30.6	30.4	30.5	30.5
Distance after Applied	43.4	43.6	44.5	43.7
Pedal Force	90.	120.	100.	140.

In Reverse:

Run Number	42	43	
Time to Stop (sec)	2.2	2.3	
Speed at Brake Applied	29.4	29.7	
Distance after Applied	49.6	53.5	
Pedal Force	120.	110.	

Camaro

Series 10 - Repeat Series 9 but hold throttle wide open.

In <u>Drive</u>:

<u>Run Number</u>	44	45	46
Time to Stop (sec)	3.2	4.4	5.5
Speed at Brake Applied	31.7	30.7	31.3
Distance after Applied	81.0	95.9	113.4
<u>Pedal Force</u>	180. max	170. max	170. max

In <u>Reverse</u>:

<u>Run Number</u>	94	95	96	97	98
Time to Stop (sec)	9.2	9.7	9.7	9.1	9.9
Speed at Brake Applied	33.8	31.6	30.5	32.5	31.0
Distance after Applied	291.6	250.2	247.1	238.9	256.7
<u>Pedal Force</u>	70. max	76 max	84 max	78 max	70. max

Series 11 - A) Measure stopping distance and pedal force from 30 mph for a 10.7 ft/sec/sec deceleration.

In <u>Drive</u>:

<u>Run Number</u>	49	50	51
Time to Stop (sec)	4.6	4.0	4.0
Speed at Brake Applied	30.4	30.3	30.3
Distance after Applied	131.1 *	93.1	92.9
<u>Pedal Force</u>	18.	18.	18.

* slower to pedal force.

In <u>Reverse</u>:

<u>Run Number</u>	52	53	54
Time to Stop (sec)	4.6	4.5	4.3
Speed at Brake Applied	29.6	29.0	29.2
Distance after Applied	100.8	100.1	91.5
<u>Pedal Force</u>	16.	18.	20.

Camaro

Series 11 - B) Measure pedal force for a 30 mph with a 10.7 ft/sec/sec deceleration (same stopping distance as A) but hold the throttle wide open.

In Drive:

Run Number	99	100	101
Time to Stop (sec)	5.7	5.2	5.5
Speed at Brake Applied	31.0	31.2	31.2
Distance after Applied	127.1	118.3	112.4
Pedal Force	128. max	124. max	160. max

In Reverse:

Run Number	102	103	104	105
Time to Stop (sec)	26.7	15.3	15.5	9.3
Speed at Brake Applied	31.4	32.0	30.6	32.9
Distance after Applied	498.2	378.8	415.2	259.8
Pedal Force	170.	140.	170.	144.

Series 11 - C) Measure stopping distance from 30 mph with the throttle held wide open but the same pedal force as measured in Series 11 - A).

In Drive:

Run Number	106		
Time ~~to Stop~~ (sec)	22.1	Will not stop car.	
Speed at Brake Applied	32.0	Held 15mph.	
Distance after Applied	544.1		
Pedal Force	18-20		

In Reverse:

Run Number	107		
Time ~~to Stop~~ (sec)	8.0	Picked up speed	
Speed at Brake Applied	31.8	during brake applicatio	
Distance after Applied	333.0	Went over 35 mph	
Pedal Force	20-30		

Series 12 - Electro-Static Discharge Tests - Identify which piece of wiring harness goes to the cruise control. Point-and-Shoot procedure to be used.

No Effect.

VEHICLE RESEARCH & TEST CENTER

TEST VEHICLE RECORD

A. DESCRIPTION

TEST NO: 78-0128 Date 11/28/88 Model Year: 1985

VIN: 1C3BT56E1FC244302 Make: Chrysler Model: New Yorker

Color: WHITE Mfg. Date: 3-85 Odometer Reading: 39662

✓ Auto Trans.
✓ Pwr. Brakes
✓ Pwr. Steering

✓ Auto Speed Control
N/A Anti-Lock Brakes
✓ Air Cond.
___ Other: Sedan 4D

Brakes:	Front	Rear
Drum		✓
Disk	✓	

Tire Size: GY Vector P185/75R14 GVWR 3842 lb

Cylinders: 4 GAWR(F) 2126

Total Displ.: 2.2L GAWR(R) 1766

FUEL INJECTION: EFI Turbo Wheelbase 103"

CARBURETOR: N/A

B. CONDITION AS RECEIVED

Vehicle History:

Condition:

C. COMMENTS:

10-17-8

TEST PROCEDURE FOR TSC TESTS VEHICLE: Chrysler

Chart recorder for speed, acceleration, rpm, brake pedal force, cruise control (c/c) vacuum, throttle position, and event versus time at 10 mm/sec. Engine at normal operating temperature for all tests.

Series 1 - C/C off; Gas pedal floored after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

Run Number	1	2	3	4
Time to 30 mph (sec)	4.4 engine bog	3.9	3.8	3.9
Total Distance Traveled	92.2	91.5	87.3	90.5
	dh	uh	dh	uh

Series 2 - C/C off; Normal idle induced creep after shifting to Drive. Go to 100 ft. Repeat twice for a total of 3 runs.

Run Number	5	6	7	8
Time to 100 ft	10.9	10.5	11.8	12.4
Final Speed	9.7	10.0	8.9	8.3
	dh	dh	uh	uh

Series 3 - C/C malfunctions after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

c/c Hit "on" button

A) Direct short to ground of c/c ~~speed sensor switch and~~ ~~vacuum pump and dump valve~~. air bleed ports plugged

Run Number	9	10	11	12
Time to 30 mph (sec)	8.9	9.3	8.4	9.1
Total Distance Traveled	230.2	238.7	215.1	238.
	dh	uh	dh	

N/A

B) Minimum speed circuit fault (Actuate Resume in Drive with a 65 mph signal). (Frequency @ ________) -105

N/A for mechanical system.

Run Number			
Time to 30 mph (sec)			
Total Distance Traveled			

Repeat B) with 130 mph signal. (Frequency @ ________) -210

Run Number			
Time to 30 mph (sec)			
Total Distance Traveled			

Chry

Series 4 - C/C off; Gas pedal floored after shifting to Drive and <u>until vehicle stops</u>. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	60lb				100lb	
	(2sec/60lb)		(2sec/60lb)		(2sec/100lb)	
Run Number	13	14	15	16	17	18
Time to Stop (sec)	3.4	3.0	2.8	2.9	2.0	1.9
Speed at Brake Applied	13.2	12.5	12.0	13.8	13.2	12.5
Distance after Applied	44.9	36.9	33.8	38.0	25.8	24.3
Total Distance Traveled	67.5	56.8	53.8	60.4	~~.02~~	~~0.4~~

	100lb		150lb		
	(2sec/100lb)		(2sec/150lb)		(2sec/150lb)
Run Number	19	20	21	22	23
Time to Stop (sec)	1.8	1.9	1.4	1.4	1.4
Speed at Brake Applied	13.1	12.8	12.5	12.7	12.1
Distance after Applied	22.9	23.2	18.2	18.1	18.5
Total Distance Traveled	44.4	~~0.2~~	38.2	38.6	38.7

	60lb					
	(1sec/60lb)		(1sec/60lb)		(1sec/100lb)	
Run Number	~~24~~	25	26	27	28	29
Time to Stop (sec)	~~5.1~~	1.6	1.5	1.5	1.0	1.0
Speed at Brake Applied	~~6.3~~	6.4	7.0	7.2	5.9	5.8
Distance after Applied	~~39.4~~	12.4	12.1	12.4	8.4	8.1
Total Distance Traveled	~~46.2~~	19.0	18.7	19.0	~~0.2~~	~~0.2~~

Idle too high

			150lb			
	(1sec/100lb)		(1sec/150lb)		(1sec/150lb)	
Run Number	30	31	32	33	34	35
Time to Stop (sec)	1.1	0.9	0.8	0.8	1.1	0.8
Speed at Brake Applied	6.9	5.1	6.0	5.2	7.7	5.9
Distance after Applied	9.2	7.3	6.8	6.9	10.1	7.4
Total Distance Traveled	~~0.2~~	~~0.2~~	12.6	12.4	17.8	13.8

Chrys

Series 5 - C/C off; Gas pedal floored after shifting to Drive but <u>release throttle when brakes are applied</u> at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)		(2sec/60lb)		(2sec/100lb)	
Run Number	36	37	38	39	40	
Time to Stop (sec)	1.0	1.0	1.0	1.0	1.0	
Speed at Brake Applied	14.4	13.6	13.8	14.7	13.4	
Distance after Applied	14.7	14.1	14.1	14.0	13.1	
Total Distance Traveled	39.2	36.7	37.2	39.1	34.8	

LU @ end }

	(2sec/100lb)		(2sec/150lb)		(2sec/150lb)	
Run Number	41	42				
Time to Stop (sec)	1.0	0.9				
Speed at Brake Applied	14.8	13.9				
Distance after Applied	13.3	12.3				
Total Distance Traveled	38.1	35.1				

LU mid way thru stop }

	(1sec/60lb)		(1sec/60lb)		(1sec/100lb)	
Run Number	43	44	45	46	47	48
Time to Stop (sec)	0.6	0.6	0.6	0.6	0.6	0.6
Speed at Brake Applied	6.7	5.2	5.0	6.5	5.9	5.9
Distance after Applied	5.0	4.3	4.2	4.7	4.4	4.0
Total Distance Traveled	11.1	9.6	9.3	10.6	9.5	9.0

	(1sec/100lb)		(1sec/150lb)		(1sec/150lb)	
Run Number	49	50	51	52	53	54
Time to Stop (sec)	0.6	0.6	0.6	0.5	0.6	0.6
Speed at Brake Applied	7.3	5.7	6.7	6.1	7.5	6.6
Distance after Applied	5.1	4.5	4.2	3.6	4.5	4.3
Total Distance Traveled	11.6	10.8	11.3	9.2	11.6	10.7

LU @ end

Same Note

Chry

Series 6 - C/C malfunction (Direct short to ground of c/c ~~speed sensor switch~~ ~~vacuum pump and dump valve~~ air bleed ports plugged) after shifting to Drive. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)		(2sec/60lb)		(2sec/100lb)	
Run Number	55	56	57	58	59	60
Time to Stop (sec)	0.9	0.6	0.8	0.6	0.8	0.6
Speed at Brake Applied	4.8	2.9	3.9	3.3	4.2	4.3
Distance after Applied	5.7	3.0	4.8	2.9	4.5	3.8
Total Distance Traveled	~~0.4~~	~~0.4~~	~~0.2~~	~~0.4~~	~~0.2~~	~~0.2~~

	(2sec/100lb)		(2sec/150lb)	(2sec/150lb)
Run Number	61	62		
Time to Stop (sec)	0.7	0.7		
Speed at Brake Applied	4.7	4.1		
Distance after Applied	3.9	3.6		
Total Distance Traveled	~~0.2~~	~~0.2~~		

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	63	64	65
Time to Stop (sec)	0.3	0.3	0.2
Speed at Brake Applied	1.2	1.3	1.1
Distance after Applied	0.9	0.8	0.6
Total Distance Traveled	~~0.2~~	~~0.2~~	~~0.3~~

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	66		
Time to Stop (sec)	0.3		
Speed at Brake Applied	1.5		
Distance after Applied	0.8		
Total Distance Traveled	~~0.2~~		

Chry

N/A for mechanical system

~~Series 7 - C/C malfunction (Minimum speed circuit fault). Actuate Resume in Drive with a 65 mph signal. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.~~

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number			
Time to Stop (sec)			
Speed at Brake Applied			
Distance after Applied			
Total Distance Traveled			

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number			
Time to Stop (sec)			
Speed at Brake Applied			
Distance after Applied			
Total Distance Traveled			

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number			
Time to Stop (sec)			
Speed at Brake Applied			
Distance after Applied			
Total Distance Traveled			

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number			
Time to Stop (sec)			
Speed at Brake Applied			
Distance after Applied			
Total Distance Traveled			

Chry

Series 8 - C/C malfunction - ~~direct short to ground of~~ c/c air bleed port plugg ~~vacuum pump but~~ dump valve vacuum plugged. Determine minimum brake pedal force to prevent vehicle movement after shifting to Drive. Apply brakes in Park and maintain that level after shifting to Drive.

#67

Brake Pedal Force	20	15	10	8		
Stopped in Drive	yes	yes	yes	no		

N/A for mechanical system

~~Electro-Static Discharge Tests - Identify which piece of wiring harness goes to the cruise control. Point-and-Shoot procedure to be used. Use 25 KV for magnetic loop and 10 KV for spark tip tests. Note results, especially if tests cause intermittent throttle opening.~~

VEHICLE RESEARCH & TEST CENTER

TEST VEHICLE RECORD

A. DESCRIPTION

1G6CD6981F4273126

TEST NO: 78-0128 Date 20 Dec '88 Model Year: 1985

VIN: Make: Cadillac Model: Sedan DeVille

Color: Burgandy Mfg. Date: 11/84 Odometer Reading: 69,779.

✓ Auto Trans.
✓ Pwr. Brakes
✓ Pwr. Steering

✓ Auto Speed Control
N/A Anti-Lock Brakes
✓ Air Cond.
Other:

Brakes:	Front	Rear
Drum		
Disk	✓	✓

Tire Size: P205/75R 14 GVWR 4577

Cylinders: V8 GAWR(F) 2578

Total Displ.: 4.1L GAWR(R) 1999

FUEL INJECTION: TBI Wheelbase

CARBURETOR:

B. CONDITION AS RECEIVED

Vehicle History: Rental

Condition:

C. COMMENTS:

10-17-

TEST PROCEDURE FOR TSC TESTS VEHICLE: Cadillac

Chart recorder for speed, acceleration, rpm, brake pedal force, cruise control (c/c) vacuum, throttle position, and event versus time at 10 mm/sec. Engine at normal operating temperature for all tests.

Series 1 - C/C off; Gas pedal floored after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

Run Number	1	2	3	4
Time to 30 mph (sec)	4.0	4.0	4.2	4.
Total Distance Traveled	102.2	103.0	108.1	108.
	dh	dh	uh	u

Series 2 - C/C off; Normal idle induced creep after shifting to Drive. Go to 100 ft. Repeat twice for a total of 3 runs.

Run Number	5	6	7	8
Time to 100 ft	28.8	26.7	18.9	18.9
Final Speed	2.7	2.9	4.4	4.3
	uh	uh	dh	dh.

Series 3 - C/C malfunctions after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

A) Direct short to ground of c/c vacuum servo solenoid valves ~~pump and dump valve~~.

Run Number	9	10	11	1
Time to 30 mph (sec)	4.0	4.0	4.2	4.
Total Distance Traveled	101.8	102.2	109.1	109.
	dh	dh	uh	uh

B) Minimum speed circuit fault (Actuate Resume in Drive with a 65 mph signal). (Frequency @ ________) ~105

Run Number			
Time to 30 mph (sec)			
Total Distance Traveled			

Repeat B) with 130 mph signal. (Frequency @ ________) ~210

Run Number			
Time to 30 mph (sec)			
Total Distance Traveled			

CIRCUIT INOPERATIVE

Cadillac

Series 4 - C/C off; Gas pedal floored after shifting to Drive and <u>until vehicle stops</u>. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	13	14	15
Time to Stop (sec)	2.2	2.1	1.8
Speed at Brake Applied	16.4	16.1	15.5
Distance after Applied	32.4	31.3	26.2
Total Distance Traveled	60.2	62.7	55.0

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	16	17	18
Time to Stop (sec)	1.8	1.6	1.6
Speed at Brake Applied	16.5	16.3	16.0
Distance after Applied	26.3	25.0	25.0
Total Distance Traveled	55.5	56.1	55.9

	(1sec/60lb)	(1sec/60lb)		(1sec/100lb)
Run Number	19	20	21	22
Time to Stop (sec)	1.4	1.2	1.2	1.0
Speed at Brake Applied	9.3	8.8	8.3	7.2
Distance after Applied	13.8	12.0	12.1	10.3
Total Distance Traveled	23.7	20.3	20.7	18.0

	(1sec/100lb)		(1sec/150lb)	(1sec/150lb)
Run Number	23	24	25	26
Time to Stop (sec)	1.1	1.1	1.0	1.0
Speed at Brake Applied	8.5	8.6	8.0	9.3
Distance after Applied	11.1	10.5	9.6	10.6
Total Distance Traveled	20.6	18.9	18.0	19.6

Cadillac

Series 5 - C/C off; Gas pedal floored after shifting to Drive but release throttle when brakes are applied at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)	
Run Number	27	28	29	
Time to Stop (sec)	1.2	1.2	1.2	
Speed at Brake Applied	18.5	19.0	19.0	
Distance after Applied	19.7	20.8	20.5	
Total Distance Traveled	54.5	58.0	58.2	mild LU

	(2sec/100lb)		(2sec/150lb)	(2sec/150lb)
Run Number	30	31	32	33
Time to Stop (sec)	1.2	1.2	1.3	1.2
Speed at Brake Applied	17.4	18.7	17.5	18.0
Distance after Applied	19.1	19.2	17.9	18.8
Total Distance Traveled	53.6	55.6	52.2	55.3
	LU.	LU.	LU.	LU.

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	34	35	36
Time to Stop (sec)	0.8	0.9	0.8
Speed at Brake Applied	10.6	11.4	10.5
Distance after Applied	9.5	10.0	8.8
Total Distance Traveled	23.1	24.2	21.2

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)	
Run Number	37	38	39	40
Time to Stop (sec)	0.8	0.8	0.8	0.8
Speed at Brake Applied	10.2	11.6	12.3	11.6
Distance after Applied	8.1	8.1	9.3	8.3
Total Distance Traveled	19.5	20.6	23.7	21.2

Cadillac

Series 6 - C/C malfunction (Direct short to ground of c/c vacuum ~~pump and~~ Servo ~~dump valve~~ solenoids) after shifting to Drive. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	41	42	43
Time to Stop (sec)	1.8	1.8	1.5
Speed at Brake Applied	13.0	13.6	13.2
Distance after Applied	22.8	24.0	20.0
Total Distance Traveled	39.7	42.1	37.8

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	44	45	46
Time to Stop (sec)	1.5	1.4	1.4
Speed at Brake Applied	13.2	13.4	13.0
Distance after Applied	20.1	18.6	17.9
Total Distance Traveled	38.2	37.1	36.3

	(1sec/60lb)		(1sec/60lb)		(1sec/100lb)	
Run Number	47	48	49	50	51	52
Time to Stop (sec)	0.9	1.1	0.9	1.0	1.0	1.0
Speed at Brake Applied	3.7	6.3	4.7	4.4	6.5	5.5
Distance after Applied	5.6	8.9	6.5	6.4	8.0	8.6
Total Distance Traveled	8.2	13.4	9.3	9.1	12.8	13.2

	(1sec/100lb)		(1sec/150lb)	(1sec/150lb)		
Run Number	53	54	55	56	57	58
Time to Stop (sec)	1.0	0.9	0.7	0.9	1.0	0.7
Speed at Brake Applied	6.3	5.3	3.7	5.6	7.2	5.7
Distance after Applied	8.2	7.8	5.5	7.3	9.6	5.6
Total Distance Traveled	13.0	12.4	8.7	11.9	16.6	9.0

(1sec/150 lb)	
0.9 sec	0.7 sec
6.3 mph	4.4 MPH
7.5′	5.4′
11.9′	8.7′
59	60

Cadillac

Series 7 - C/C malfunction (Minimum speed circuit fault). Actuate Resume in Drive with a 65 mph signal. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

Circuit Inoperative

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number			
Time to Stop (sec)			
Speed at Brake Applied			
Distance after Applied			
Total Distance Traveled			

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number			
Time to Stop (sec)			
Speed at Brake Applied			
Distance after Applied			
Total Distance Traveled			

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number			
Time to Stop (sec)			
Speed at Brake Applied			
Distance after Applied			
Total Distance Traveled			

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number			
Time to Stop (sec)			
Speed at Brake Applied			
Distance after Applied			
Total Distance Traveled			

Cadillac

Series 8 - C/C malfunction - direct short to ground of c/c vacuum servo ~~pump but dump valve vacuum plugged.~~ Determine minimum brake pedal force to prevent vehicle movement after shifting to Drive. Apply brakes in Park and maintain that level after shifting to Drive.

Brake Pedal Force	20	25	27	26	25	24	25
Stopped in Drive	No	No	Yes	Yes	Yes	No	*

*Crept a few inches then stopped.

Electro-Static Discharge Tests - Identify which piece of wiring harness goes to the cruise control. Point-and-Shoot procedure to be used. Use 25 KV for magnetic loop and 10 KV for spark tip tests. Note results, especially if tests cause intermittent throttle opening.

Spark to Chassis (not wiring harness) — see note below:
Magnetic field in engine compartment — no effect

NOTE: When the 25KV spark was applied to the alternator case, engine speed increased slightly because of Idle Speed Control (ISC) motor reaction.

VEHICLE RESEARCH & TEST CENTER

TEST VEHICLE RECORD

A. DESCRIPTION

TEST NO: 78-0128 Date 12/12/88 Model Year: 1985

VIN: JN1HZ14S4FX097474 Make: Nissan Model: 300ZX

Color: White Mfg. Date: 6/85 Odometer Reading: 33,282.

✓ Auto Trans.
✓ Pwr. Brakes
✓ R.W. Drive
✓ Pwr. Steering

✓ Auto Speed Control
___ Anti-Lock Brakes
✓ Air Cond.
___ Other: Non-Turbo ; Analog Speedo

Brakes:	Front	Rear
Drum		
Disk	✓	✓

Bridgestone Potenza
Tire Size: P215/60R15 GVWR 3580

Cylinders: V6 GAWR(F) 1720

Total Displ.: 3.0L GAWR(R) 1860

FUEL INJECTION: AFC Wheelbase 91.3"
CARBURETOR: ______

B. CONDITION AS RECEIVED

Vehicle History: Leased from Buckeye Ford London Ohio

Condition: Good

C. COMMENTS:

12-17-8

TEST PROCEDURE FOR TSC TESTS VEHICLE: 300ZX

Chart recorder for speed, acceleration, rpm, brake pedal force, cruise control (c/c) vacuum, throttle position, and event versus time at 10 mm/sec. Engine at normal operating temperature for all tests.

Series 1 - C/C off; Gas pedal floored after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

Run Number	1	2	3	4
Time to 30 mph (sec)	3.9	3.9	4.2	4.
Total Distance Traveled	95.7	96.0	101.8	103.
	dh	dh	uh	u

Series 2 - C/C off; Normal idle induced creep after shifting to Drive. Go to 100 ft. Repeat twice for a total of 3 runs.

Run Number	5	6	7	8
Time to 100 ft	13.8	14.0	17.3	17.4
Final Speed	6.7	6.5	5.0	5.0
	dh	dh	uh	uh

Series 3 - C/C malfunctions after shifting to Drive. Go to 30 mph and repeat twice for a total of 3 runs.

A) Direct short to ground of c/c vacuum pump and dump valve.

Run Number	39	40	41	42
Time to 30 mph (sec)	4.8	4.8	5.1	5.
Total Distance Traveled	119.4	119.8	132.3	130.
	dh	dh	uh	u

B) Minimum speed circuit fault (Actuate Resume in Drive with a 65 mph signal). (Frequency @ 40) ~105

Run Number	43	44	45	46
Time to 30 mph (sec)	5.7	8.0	7.7	7.
Total Distance Traveled	147.0	201.5	194.5	173.
	dh	uh	uh	d

Repeat B) with 130 mph signal. (Frequency @ 42) ~210

Run Number	47@45Hz	48	49	50	51	52
Time to 30 mph (sec)	10.2	7.0	7.0	7.0	8.0	7.
Total Distance Traveled	288.2	172.3	173.2	171.4	201.2	196.
	uh	dh	dh	dh	uh	u

300ZX

Series 4 - C/C off; Gas pedal floored after shifting to Drive and <u>until vehicle stops</u>. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

(2 sec/60 lb.)			(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
15	16	Run Number	9	10	11
2.5	2.6	Time to Stop (sec)	2.6	2.7	2.2
15.1	16.1	Speed at Brake Applied	16.8	17.2	15.7
33.9	35.8	Distance after Applied	36.9	38.7	29.4
60.6	63.1	Total Distance Traveled	66.1	68.7	54.8

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	12	13	14
Time to Stop (sec)	2.1	2.1	2.2
Speed at Brake Applied	15.0	14.9	15.0
Distance after Applied	26.7	28.7	29.5
Total Distance Traveled	49.4	54.1	55.8

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	17	18	19
Time to Stop (sec)	1.6	1.7	1.7
Speed at Brake Applied	7.0	8.5	9.8
Distance after Applied	13.9	14.6	17.9
Total Distance Traveled	20.6	21.9	29.1

	(1sec/100lb)		(1sec/150lb)	(1sec/150lb)
Run Number	20	21	22	23
Time to Stop (sec)	1.4	1.5	1.4	1.3
Speed at Brake Applied	6.9	7.7	7.6	7.2
Distance after Applied	12.2	13.8	12.4	11.0
Total Distance Traveled	18.9	22.1	20.6	18.3

300ZX

Series 5 - C/C off; Gas pedal floored after shifting to Drive but release throttle when brakes are applied at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	24	25	26
Time to Stop (sec)	1.0	0.9	0.9
Speed at Brake Applied	14.9	15.4	15.0
Distance after Applied	13.6	13.6	12.2
Total Distance Traveled	41.0	42.3	39.1

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)	
Run Number	27	28	29	30
Time to Stop (sec)	0.9	0.8	0.8	0.8
Speed at Brake Applied	14.6	14.9	15.1	15.1
Distance after Applied	12.5	11.8	11.8	11.6
Total Distance Traveled	39.1	—	37.2	38.4

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	31	32	33
Time to Stop (sec)	0.7	0.7	0.6
Speed at Brake Applied	10.1	10.0	8.2
Distance after Applied	7.5	6.8	6.6
Total Distance Traveled	18.6	16.9	16.1

	(1sec/100lb)		(1sec/150lb)	(1sec/150lb)	
Run Number	34	35	36	37	38
Time to Stop (sec)	0.6	0.6	0.6	0.6	0.6
Speed at Brake Applied	10.0	8.7	9.8	9.3	8.8
Distance after Applied	6.7	6.6	5.9	6.2	5.6
Total Distance Traveled	17.5	17.2	15.8	16.6	14.8

300ZX

Series 6 - C/C malfunction (Direct short to ground of c/c vacuum pump and dump valve) after shifting to Drive. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each.

	(2sec/60lb)	(2sec/60lb)		(2sec/100lb)
Run Number	53	54	55	56
Time to Stop (sec)	3.0	2.5	2.1	2.6
Speed at Brake Applied	12.5	12.3	12.0	12.7
Distance after Applied	35.0	29.1	24.6	31.2
Total Distance Traveled	— *	45.7	— *	— *

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	57		
Time to Stop (sec)	2.6		
Speed at Brake Applied	12.7		
Distance after Applied	30.5		
Total Distance Traveled	— *		

* Front wheel Lock up

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	58	59	60
Time to Stop (sec)	1.0	0.8	0.9
Speed at Brake Applied	3.3	4.2	3.4
Distance after Applied	5.9	4.9	4.9
Total Distance Traveled	—	—	—

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	61	62	63
Time to Stop (sec)	0.8	0.8	0.8
Speed at Brake Applied	3.6	4.7	4.6
Distance after Applied	4.7	4.6	4.5
Total Distance Traveled	—	8.2	7.8

300ZX

Series 7 - C/C malfunction (Minimum speed circuit fault). Actuate Resume in Drive with a 65 mph signal. Apply brakes at specified pedal forces and time delays. Allow a minimum of 3 minutes between stops for brake cooling. Repeat for a total of 2 runs each. 40 Hz

	(2sec/60lb)	(2sec/60lb)	(2sec/100lb)
Run Number	64	65	66
Time to Stop (sec)	0.7	0.8	0.6
Speed at Brake Applied	8.6	10.4	9.5
Distance after Applied	6.3	7.7	6.5
Total Distance Traveled	23.1	31.7	25.6

	(2sec/100lb)	(2sec/150lb)	(2sec/150lb)
Run Number	67	68	69
Time to Stop (sec)	0.7	0.6	0.6
Speed at Brake Applied	9.0	9.0	9.3
Distance after Applied	6.4	5.6	6.0
Total Distance Traveled	25.1	22.0	24.5

	(1sec/60lb)	(1sec/60lb)	(1sec/100lb)
Run Number	70	71	72
Time to Stop (sec)	0.5	0.5	0.4
Speed at Brake Applied	4.9	4.5	5.2
Distance after Applied	3.0	3.1	2.8
Total Distance Traveled	8.0	8.4	8.9

	(1sec/100lb)	(1sec/150lb)	(1sec/150lb)
Run Number	73	74	75
Time to Stop (sec)	0.4	0.4	0.4
Speed at Brake Applied	5.3	5.2	5.2
Distance after Applied	2.9	2.8	2.7
Total Distance Traveled	8.7	8.1	8.4

300 ZX

Series 8 - C/C malfunction - direct short to ground of c/c vacuum pump but dump valve vacuum plugged. Determine minimum brake pedal force to prevent vehicle movement after shifting to Drive. Apply brakes in Park and maintain that level after shifting to Drive.

Brake Pedal Force	20	25	24	23		
Stopped in Drive	No	Yes	Yes	No		

Electro-Static Discharge Tests - Identify which piece of wiring harness goes to the cruise control. Point-and-Shoot procedure to be used. Use 25 KV for magnetic loop and 10 KV for spark tip tests. Note results, especially if tests cause intermittent throttle opening.

Photos
Magnetic loop @ 25Kv & 20Kv spark to servo & module areas; No effect on throttle or engine speed.

APPENDIX F

Bench Test Procedures
For Cruise Controls and Sample Output

Background

It has frequently been alleged that Sudden Acceleration results from mysterious intermittent defects of the electronic engine controls in certain vehicles which are somehow undetectable upon testing after an incident. Although the preponderance of evidence suggests that pedal misapplications are responsible for virtually all SA incidents where a defect can not be found after the fact, TSC nonetheless agreed to conduct long-duration tests of selected cruise controls to determine whether any of them might exhibit an occasional throttle-opening malfunction.

Intermittent malfunctions in electronic devices are generally much more difficult to diagnose than steady-state failures. (The latter are also referred to as "hard" or repeatable failures.) The difficulty in diagnoses is inversely proportional to the frequency of occurrence of the malfunction.

When service engineers must respond to end-user complaints of rarely occurring intermittents, they frequently invoke one or more techniques designed to increase the frequency of occurrence of an intermittent condition. Among these are:

1. Temperature variations, especially transitions between the maximum and minimum temperature design limits of the device in question;
2. Variations in power supply voltages;
3. Shock and vibration;
4. Exposure of the device under test to electro-magnetic interference (EMI) of a nature that might possibly be generated by other devices in the same system, e.g., other parts, possibly defective parts, of a car's electrical system;
5. Exposure to radio-frequency interference (RFI) of such strength and frequency as might possibly be encountered arising from some external source.

Sudden acceleration is an extreme case of a rarely occurring phenomenon. In most case reports there is but a single incident over the lifetime of a given vehicle. Therefore, it is appropriate to use every possible means of amplifying the probability of occurrence of incidents.

Objectives

In light of the considerations discussed above, the objective of this testing became simply to determine whether long-term testing of cruise controls could show any evidence of intermittent malfunctions leading to throttle opening. Extremes of temperature, supply voltage variation and exposure to EMI/RFI would all be employed in an attempt to induce these failures.

Since most SA incidents occur at the moment a vehicle is shifted into gear from "Park," it is appropriate that the testing concentrate on simulating the conditions that the cruise control would experience at that moment. Indeed the majority of failures in all kinds of electronic equipment occur at the moment power is applied or within a few seconds afterward. Therefore the testing should incorporate a large number of power on-off cycles, preferably exceeding the number experienced by the average vehicle over it's lifetime. Other electrical transients, such as the spike from the air-conditioner clutch, should also be presented for large numbers of trials.

The large numbers of trials over an extended period of time necessitated the use of fully automated, computer-controlled test procedures. These facilitated the second objective, which was to document the status of all variables at the instant of any malfunction and to preserve oscillographic records of the incident.

Procedures

To explore the possibilities for automated testing of cruise controls, a minimal test jig was constructed first. This device included the vacuum servo and switches for all inputs, but did not operate in closed-loop mode, i.e. the speed input to the cruise control was driven from an external pulse generator and was uncorrelated with the action of the vacuum servo.

Preliminary experiments with this test jig placed inside an environmental chamber showed that operation at temperature extremes and power supply variations should present no problems, but that strong RFI sources would cause momentary disturbances of the sort depicted in Figure 3.1.2-2.

The surplus environmental chamber used for this work was modified to operate under remote control by computer. Unfortunately, it was found to be too small to install a shaker table for controlled vibration studies. However, an unbalanced fan in the chamber provided a substantial amount of natural vibration .

The fully automated system, including the following features, was then designed.

1. Closed-loop operation of the cruise-control as a system using a linear-potentiometer attached to the vacuum servo and a voltage-to-frequency converter as the feedback element. A 3.3-second time constant in the converter approximated the lag in speed to changes in throttle position of a real vehicle;

2. Recording and/or control of all inputs and outputs to the cruise control using the "Labtech Notebook" data acquisition system running on an XT-type personal computer. This software was set up to generate continuous screen displays of inputs and outputs (see example in Figure E-4) as well as a tabular data file;

3. Recording of any anomalous outputs from the cruise control using a personal-computer-based digital-memory oscilloscope;

4. Computerized control of temperature cycling between the upper and lower extremes.

Figure F-1 is a photograph of the complete test system, while Figure F-2 is a closeup of the test-jig only.

Figure F-1: Overall view of the cruise-control test apparatus. The major components include a carbon-dioxide-chilled environmental chamber capable of producing temperatures from -80 to +200 degrees Fahrenheit, power supplies for the device under test and for the test-jig electronics, the test jig itself, two personal computers (one for the data acquisition system on the right, the other serving as a digital memory oscilloscope on the left), an Audi air-conditioner compressor (whose clutch assembly generates a realistic EMI spike) located beneath the bench and out of view and a CB transmitter (which serves as a realistic source of RFI).

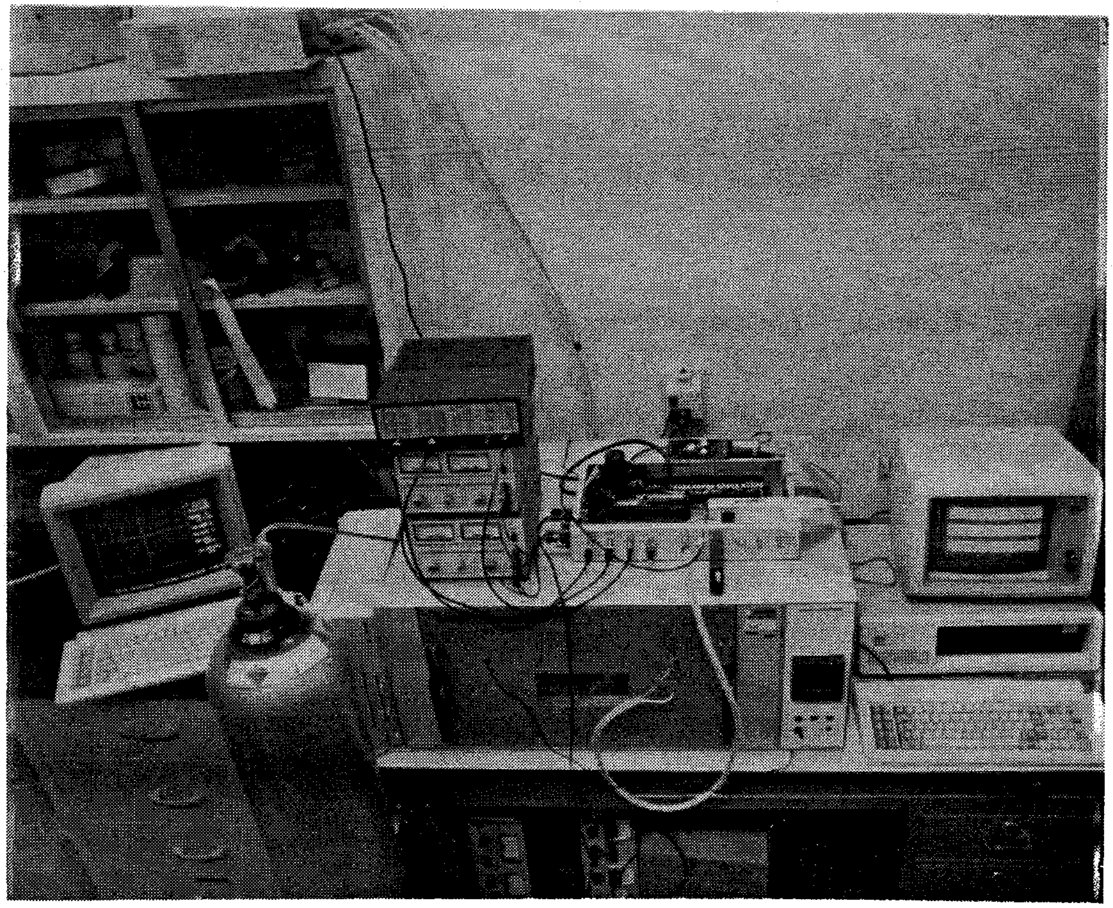
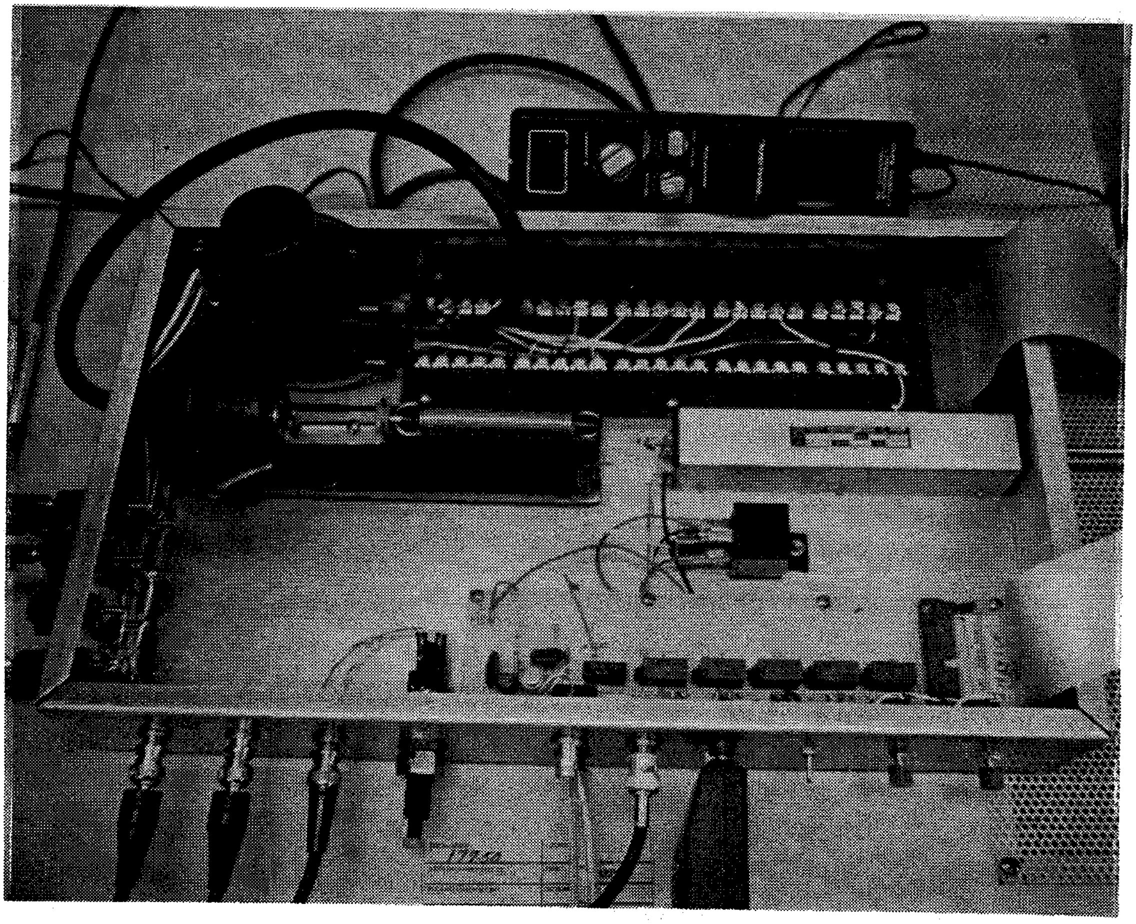


Figure F-2: Close-up view of the cruise-control test jig. The vacuum pump is at the upper left, with the servo just below it. The oblong box at right center is the linear potentiometer which measures the amount of throttle opening. The relays controlling the various test conditions, voltage-to-frequency converter, and input/output connections appear in the lower part of the photo. Also visible is the CB transmitter at the top.



A high-voltage discharge device was considered as a source for EMI/RFI. In numerous manual tests it was able to cause brief disruptions of cruise-control operation such as shown in Figure 3.1.2-2, but not able to cause sustained throttle openings which could cause an SAI. Unfortunately, it invariably caused malfunctions in the data acquisition system and thus could not be used in the automated testing.

A typical test series was carried out as follows:

1. The cruise control under test was installed inside the environmental chamber and attached to the test jig. The antenna for the RFI source and a temperature probe fastened to the case of the cruise control were the only other objects inside the chamber.

2. At least one day of testing was conducted at supply voltages of 10, 12, 14 and 16 volts. A two-ohm resistor was inserted to simulate a faulty connection during a portion of each test day. On weekends or holidays, tests were permitted to run longer.

3. The basic test sequence consisted of forty steps with the input conditions varied as shown in Table F-1. The test was executed at one step per second.

4. Temperature was raised or lowered in alternate periods. Thus each temperature cycle consisted of a 54-minute baking at 150 degrees F (81 executions of the basic test sequence) followed by a six-minute freezing at 0 degrees F. (nine passes through the basic test sequence).

5. A 50-pound cylinder of CO_2 provided sufficient refrigeration for approximately six freezing cycles down to zero degrees Fahrenheit. For the remainder of each day's testing, the chamber remained in the 140-150 degree range. About 22 hours of total running time was accumulated each day.

Under these procedures, each unit was exposed to a large number of temperature cycles more extreme than any encountered on Earth. Each controller was exposed to at least 10,000 passes through the basic test sequence. Power was switched on and off at least 10,000 times, "set" and "resume" were engaged at least 60,000 times, and bursts of RFI and EMI were applied at least 120,000 times. Although statistics on the use of cruise controls were unavailable, it seems safe to assume that the number of actuations employed in this testing substantially exceeded those that would be experienced over the lifetime of a normal vehicle. For example, if a cruise-control unit were used twice a day every day for ten years, the total number of on-off cycles would be 7,300.

Table F-1: Basic 40-second test sequence. A given condition is "on" when a "1" appears in its column, and "off" when a "0" occurs. The binary number formed by these ones and zeros is translated into its decimal value in the last column, "Condition Code," which also appears in Table F-1.

Time (sec)	Resume	Set	Power	RFI	EMI	Cond Code
1	0	0	1	0	0	4
2	0	0	1	0	0	4
3	0	1	1	0	0	12
4	1	0	1	0	0	20
5	0	1	1	0	0	12
6	1	0	1	0	0	20
7	0	1	1	0	0	12
8	1	0	1	0	0	20
9	0	1	1	0	0	12
10	1	0	1	0	0	20
11	0	1	1	0	0	12
12	1	0	1	0	0	20
13	0	0	1	0	1	5
14	0	0	1	1	0	6
15	0	0	1	0	1	5
16	0	0	1	1	0	6
17	0	0	1	0	1	5
18	0	0	1	1	0	6
19	0	0	1	0	1	5
20	0	0	1	1	0	6
21	0	0	1	0	1	5
22	0	0	1	1	0	6
23	0	1	1	0	1	13
24	0	1	1	1	0	14
25	0	1	1	0	1	13

Table F-1: (cont.)

Time (sec)	Resume	Set	Power	RFI	EMI	Cond Code
26	0	1	1	1	0	14
27	0	1	1	0	1	13
28	0	1	1	1	0	14
29	0	1	1	0	1	13
30	0	1	1	1	0	14
31	0	1	1	0	1	13
32	0	1	1	1	0	14
33	1	0	1	0	1	21
34	1	0	1	1	0	22
35	1	0	1	0	1	21
36	1	0	1	1	0	22
37	1	0	1	0	1	21
38	1	0	1	1	0	22
39	0	0	0	0	0	0
40	0	0	0	0	0	0

An alarm feature in the "Labtech Notebook" software generated a special file marker if a throttle opening of more than 0.25 inches occurred (WOT is 1.6 inches). Data would be saved if this marker ever appeared, but otherwise it was discarded at the end of each temperature half-cycle.

Two of the units tested were removed from Audi 5000's whose owners had complained of SA incidents, while two others were new and unused.

Results None of the units exhibited any malfunctions that would result in throttle opening during the tests described above. Table F-2 shows the printout from one six-minute chilling. In this run, the vacuum servo was deliberately pushed in by hand a few seconds after the start in order to trigger the data saving process and also to provide this example for illustration of the methodology. The remainder of the run was normal. Figure F-3 shows the "Labtech Notebook" screen display just after the incident, while Figure F-4 shows the same incident as recorded by the digital memory oscilloscope.

In the course of testing, some of the cruise controls were damaged so that they would no longer function at all. One unit intermittently "forgot" the set speed when exposed to strong RFI fields. However, there was never any indication whatsoever of an unsafe failure mode.

The strong EMI/RFI fields and/or vibration caused malfunction in the temperature controller for the environmental chamber on two occasions, leading to the destruction of cruise controls by melting or incineration of their plastic parts.

Table F-2: Sample of one six-minute chilling cycle. A deliberate anomaly was introduced at the beginning of the test by pushing the vacuum-servo in by hand in order to trigger data saving and thereby illustrate the methodology. Although the throttle-position change began at time zero, the cruise control did not actually engage until the first sustained "Set" command occurred at 23 seconds. Operation of the vacuum pump also triggered the digital memory oscilloscope producing the record of the event shown in Figure F-4. The vent released at 26 seconds, allowing vacuum to dissipate. At 33 seconds, the throttle had returned to its closed position. The remainder of the run shows no anomalies.

Note that there is considerable variability in the temperature readings. This is an artifact caused by the coupling of switching transients from the EMI source into the temperature measurement instrumentation. The temperature readings taken at the beginning of each cycle ("condition code" = "4") are valid since no transients occur in this portion of the cycle.

"CRUISE CONTROL TEST DATA"
"The time is 10:14:21.26."
"The date is 12-21-1988."

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
0.00	4	146	16.03	0	0.05	15.98	15.18	0
1.00	4	146	16.03	0	0.54	15.98	15.18	5
2.00	12	146	16.03	0	0.61	15.98	15.18	13
3.00	20	146	16.03	0	1.12	15.99	15.18	23
4.00	12	146	16.03	0	0.99	15.98	15.19	38
5.00	20	146	16.03	0	0.93	15.98	15.18	47
6.00	12	146	16.03	0	0.90	15.98	15.18	52
7.00	20	146	16.03	0	0.87	16.00	15.20	57
8.00	12	142	16.03	0	0.85	15.98	15.18	58
9.00	20	142	16.03	0	0.83	15.98	15.18	60
10.00	12	142	16.03	0	0.80	15.98	15.18	61
11.00	20	142	16.03	0	0.76	15.98	15.18	60
12.00	5	137	16.03	0	0.74	15.98	15.18	60

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
13.00	6	142	15.96	0	0.73	15.91	15.11	58
14.00	5	166	16.09	0	0.72	16.01	15.24	58
15.00	6	137	15.91	0	0.68	15.91	15.11	57
16.00	5	161	16.09	0	0.68	16.01	15.23	56
17.00	6	137	15.96	0	0.67	15.91	15.11	54
18.00	5	166	16.10	0	0.67	16.00	15.23	53
19.00	6	137	15.96	0	0.65	15.91	15.10	53
20.00	5	156	16.08	0	0.65	16.00	15.24	52
21.00	6	142	15.96	0	0.64	15.91	15.12	50
22.00	13	166	16.09	0	0.64	16.01	15.23	51
23.00	14	142	15.96	1	0.95	10.62	0.22	50
24.00	13	171	16.08	1	0.88	15.98	0.29	54
25.00	14	137	15.96	1	1.01	15.90	0.21	57
26.00	13	137	16.03	1	0.86	15.98	15.18	61
27.00	14	137	15.96	1	0.28	15.91	15.10	61
28.00	13	166	16.08	1	0.69	16.01	15.21	55
29.00	14	132	15.96	1	0.59	15.91	15.10	53
30.00	13	166	16.11	1	0.52	16.02	15.22	51
31.00	14	132	15.96	1	0.11	15.91	15.11	47
32.00	21	181	16.13	1	0.07	16.04	15.24	39
33.00	22	132	15.96	1	0.03	15.91	15.11	29
34.00	21	171	16.10	1	0.04	16.04	15.25	22
35.00	22	132	15.96	1	0.03	15.91	15.11	17
36.00	21	176	16.11	1	0.04	16.04	15.26	14
37.00	22	137	15.96	1	0.03	15.91	15.11	10
38.00	0	181	16.11	1	0.04	16.04	15.25	9
39.00	0	132	16.03	1	0.03	15.99	15.18	7
40.00	4	132	16.03	1	0.03	15.99	15.18	5
41.00	4	132	16.03	1	0.03	15.98	15.18	5

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
42.00	12	127	16.04	1	0.03	15.98	15.18	4
43.00	20	156	16.03	1	0.03	15.99	15.18	4
44.00	12	127	16.03	1	0.02	15.99	15.18	3
45.00	20	127	16.03	1	0.02	15.98	15.18	3
46.00	12	127	16.03	1	0.02	15.98	15.18	3
47.00	20	127	16.03	1	0.02	15.98	15.18	2
48.00	12	127	16.03	1	0.02	15.98	15.18	3
49.00	20	127	16.03	1	0.02	15.98	15.18	2
50.00	12	127	16.03	1	0.02	15.98	15.18	2
51.00	20	127	16.04	1	0.02	15.98	15.18	2
52.00	5	137	16.03	1	0.02	15.99	15.18	2
53.00	6	127	15.96	1	0.02	15.91	15.11	2
54.00	5	170	16.15	1	0.03	16.04	15.28	2
55.00	6	142	15.96	1	0.02	15.91	15.11	2
56.00	5	171	16.15	1	0.03	16.04	15.27	2
57.00	6	137	15.96	1	0.02	15.91	15.12	2
58.00	5	171	16.16	1	0.03	16.05	15.27	2
59.00	6	137	15.96	1	0.02	15.91	15.11	2
60.00	5	170	16.16	1	0.04	16.06	15.30	2
61.00	6	132	15.96	1	0.02	15.91	15.11	2
62.00	13	156	16.14	1	0.04	16.06	15.28	2
63.00	14	137	15.96	1	0.02	15.91	15.11	2
64.00	13	161	16.15	0	0.03	16.06	15.28	2
65.00	14	122	15.96	1	0.02	15.91	15.11	2
66.00	13	156	16.15	1	0.03	16.05	15.26	3
67.00	14	122	15.96	1	0.02	15.91	15.12	2
68.00	13	156	16.17	1	0.04	16.06	15.25	2
69.00	14	122	15.93	1	0.02	15.91	15.12	2
70.00	13	156	16.14	1	0.04	16.06	15.28	2

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
71.00	14	117	15.96	1	0.02	15.91	15.11	2
72.00	21	146	16.16	1	0.04	16.07	15.27	3
73.00	22	117	15.96	1	0.02	15.91	15.11	2
74.00	21	146	16.11	1	0.04	16.04	15.27	3
75.00	22	117	15.96	1	0.02	15.91	15.11	2
76.00	21	146	16.11	1	0.03	16.04	15.25	2
77.00	22	117	15.97	1	0.02	15.91	15.11	2
78.00	0	150	16.11	1	0.03	16.04	15.26	2
79.00	0	117	16.03	1	0.02	15.99	15.19	2
80.00	4	112	16.03	1	0.02	15.99	15.18	2
81.00	4	112	16.03	1	0.02	15.99	15.19	1
82.00	12	117	16.03	1	0.02	15.98	15.18	2
83.00	20	117	16.03	1	0.02	15.99	15.18	2
84.00	12	117	16.03	1	0.02	15.99	15.18	2
85.00	20	117	16.00	1	0.02	15.98	15.18	1
86.00	12	117	16.03	1	0.02	15.98	15.19	2
87.00	20	117	16.03	1	0.02	15.98	15.18	2
88.00	12	117	16.03	1	0.02	15.98	15.19	1
89.00	20	117	16.03	1	0.02	15.99	15.18	2
90.00	12	117	16.04	1	0.02	15.98	15.18	1
91.00	20	117	16.03	1	0.02	15.99	15.18	2
92.00	5	117	16.03	1	0.02	15.98	15.18	1
93.00	6	117	15.96	1	0.02	15.91	15.12	2
94.00	5	137	16.16	1	0.03	16.05	15.30	2
95.00	6	112	15.96	1	0.02	15.91	15.12	1
96.00	5	137	16.03	1	0.02	15.99	15.18	2
97.00	6	107	15.96	1	0.02	15.91	15.11	1
98.00	5	127	16.16	1	0.03	16.04	15.28	2
99.00	6	107	15.96	1	0.02	15.91	15.11	1

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
100.00	5	127	16.13	1	0.03	16.05	15.27	3
101.00	6	107	15.96	1	0.02	15.91	15.11	1
102.00	13	127	16.16	1	0.03	16.05	15.27	3
103.00	14	107	15.96	1	0.02	15.91	15.11	1
104.00	13	122	16.15	1	0.03	16.04	15.26	2
105.00	14	103	15.96	1	0.02	15.91	15.12	1
106.00	13	117	16.14	1	0.03	16.06	15.27	4
107.00	14	103	15.95	1	0.02	15.91	15.12	1
108.00	13	117	16.15	1	0.03	16.06	15.25	2
109.00	14	103	15.96	1	0.02	15.91	15.11	1
110.00	13	117	16.14	1	0.03	16.04	15.27	2
111.00	14	103	15.96	1	0.02	15.91	15.11	1
112.00	21	103	16.16	1	0.03	16.07	15.27	3
113.00	22	103	15.96	1	0.02	15.91	15.11	1
114.00	21	137	16.13	1	0.03	16.04	15.26	3
115.00	22	98	15.96	1	0.02	15.91	15.12	1
116.00	21	127	16.11	1	0.03	16.04	15.26	3
117.00	22	98	15.96	1	0.02	15.91	15.12	1
118.00	0	127	16.11	1	0.03	16.04	15.27	2
119.00	0	98	16.03	1	0.02	15.98	15.19	1
120.00	4	98	16.03	1	0.02	15.99	15.19	1
121.00	4	98	16.04	1	0.02	15.98	15.16	2
122.00	12	98	16.03	1	0.02	15.99	15.19	1
123.00	20	98	16.03	1	0.02	15.99	15.18	2
124.00	12	98	16.03	1	0.02	15.98	15.19	1
125.00	20	98	16.03	1	0.02	15.98	15.18	2
126.00	12	98	16.03	1	0.02	15.98	15.19	1
127.00	20	93	16.03	1	0.02	15.99	15.18	2
128.00	12	98	16.03	1	0.02	15.98	15.18	1

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
129.00	20	93	16.03	1	0.02	15.98	15.19	2
130.00	12	93	16.03	1	0.02	15.98	15.18	1
131.00	20	93	16.03	1	0.02	15.98	15.19	2
132.00	5	98	16.03	1	0.02	15.99	15.18	1
133.00	6	93	15.94	1	0.02	15.91	15.11	2
134.00	5	127	16.16	1	0.03	16.06	15.30	1
135.00	6	93	15.96	1	0.02	15.91	15.11	1
136.00	5	137	16.15	1	0.03	16.04	15.29	2
137.00	6	88	15.96	1	0.02	15.91	15.11	1
138.00	5	132	16.03	1	0.02	15.99	15.19	2
139.00	6	88	15.96	1	0.02	15.91	15.11	1
140.00	5	132	16.17	1	0.03	16.06	15.28	2
141.00	6	88	15.97	1	0.02	15.91	15.12	1
142.00	13	127	16.17	1	0.03	16.04	15.28	2
143.00	14	88	15.96	1	0.02	15.91	15.12	1
144.00	13	107	16.15	1	0.03	16.05	15.26	2
145.00	14	88	15.96	1	0.02	15.91	15.11	1
146.00	13	127	16.14	1	0.03	16.06	15.26	2
147.00	14	88	15.96	1	0.02	15.91	15.11	1
148.00	13	122	16.16	1	0.03	16.05	15.28	2
149.00	14	83	15.96	1	0.02	15.91	15.11	1
150.00	13	122	16.16	1	0.03	16.05	15.27	2
151.00	14	83	15.96	1	0.02	15.91	15.12	1
152.00	21	122	16.15	1	0.03	16.06	15.28	2
153.00	22	83	15.97	1	0.02	15.91	15.12	1
154.00	21	122	16.11	1	0.03	16.04	15.26	2
155.00	22	83	15.96	1	0.02	15.91	15.12	1
156.00	21	117	16.10	1	0.03	16.04	15.26	2
157.00	22	88	15.96	1	0.02	15.91	15.11	1

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
158.00	0	127	16.12	1	0.03	16.04	15.27	2
159.00	0	83	16.03	1	0.02	15.98	15.18	1
160.00	4	78	16.03	1	0.02	15.99	15.20	2
161.00	4	78	16.03	1	0.02	15.99	15.18	1
162.00	12	78	16.03	1	0.02	15.99	15.19	2
163.00	20	78	16.03	1	0.02	15.99	15.19	1
164.00	12	78	16.03	1	0.02	15.99	15.18	2
165.00	20	78	16.03	1	0.02	15.99	15.19	1
166.00	12	78	16.03	1	0.02	15.99	15.19	2
167.00	20	78	16.03	1	0.02	15.98	15.19	1
168.00	12	73	16.03	1	0.02	15.99	15.18	2
169.00	20	78	16.03	1	0.02	15.99	15.18	1
170.00	12	73	16.03	1	0.02	15.99	15.19	2
171.00	20	73	16.03	1	0.02	15.96	15.18	1
172.00	5	73	16.03	1	0.02	15.98	15.19	2
173.00	6	73	15.96	1	0.02	15.83	15.12	1
174.00	5	122	16.14	1	0.03	16.05	15.28	2
175.00	6	73	15.96	1	0.02	15.92	15.12	2
176.00	5	117	16.15	1	0.03	16.05	15.27	2
177.00	6	73	15.96	1	0.02	15.91	15.12	1
178.00	5	117	16.15	1	0.03	16.04	15.27	1
179.00	6	73	15.96	1	0.02	15.91	15.12	2
180.00	5	107	16.14	1	0.03	16.05	15.28	3
181.00	6	73	15.96	1	0.02	15.91	15.12	1
182.00	13	107	16.14	1	0.03	16.04	15.26	2
183.00	14	73	15.96	1	0.02	15.91	15.12	2
184.00	13	117	16.14	1	0.03	16.05	15.27	2
185.00	14	73	15.96	1	0.02	15.91	15.12	1
186.00	13	107	16.13	1	0.03	16.05	15.26	1

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
187.00	14	68	15.97	1	0.02	15.92	15.12	2
188.00	13	103	16.13	1	0.03	16.06	15.27	2
189.00	14	68	15.96	1	0.02	15.91	15.12	1
190.00	13	103	16.14	1	0.03	16.04	15.26	1
191.00	14	68	15.96	1	0.02	15.91	15.12	2
192.00	21	103	16.16	1	0.03	16.05	15.27	2
193.00	22	73	15.96	1	0.02	15.91	15.11	1
194.00	21	107	16.10	1	0.03	16.04	15.26	1
195.00	22	68	15.96	1	0.02	15.91	15.12	2
196.00	21	103	16.03	1	0.02	15.99	15.19	2
197.00	22	68	15.96	1	0.02	15.90	15.12	1
198.00	0	107	16.10	1	0.03	16.04	15.24	1
199.00	0	63	16.03	1	0.02	15.98	15.19	2
200.00	4	63	16.03	1	0.02	15.98	15.19	1
201.00	4	63	16.04	1	0.02	15.98	15.19	2
202.00	12	63	16.03	1	0.02	15.98	15.19	1
203.00	20	63	16.03	1	0.02	15.98	15.18	2
204.00	12	63	16.03	1	0.02	15.98	15.19	1
205.00	20	63	16.03	1	0.02	15.98	15.19	2
206.00	12	63	16.03	1	0.02	15.98	15.19	1
207.00	20	63	16.03	1	0.02	15.98	15.19	2
208.00	12	63	16.03	1	0.02	15.98	15.19	1
209.00	20	63	16.03	1	0.02	15.98	15.19	2
210.00	12	68	16.03	1	0.02	15.98	15.19	1
211.00	20	63	16.03	1	0.02	15.98	15.19	2
212.00	5	68	16.03	1	0.02	15.92	15.19	1
213.00	6	63	15.96	1	0.02	15.91	15.12	1
214.00	5	98	16.15	1	0.03	16.04	15.29	2
215.00	6	59	15.96	1	0.02	15.91	15.12	1

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
216.00	5	93	16.03	1	0.02	15.98	15.19	2
217.00	6	59	15.96	1	0.02	15.91	15.12	1
218.00	5	98	16.16	1	0.03	16.04	15.32	2
219.00	6	59	15.96	1	0.02	15.91	15.12	1
220.00	5	93	16.15	1	0.03	16.04	15.29	2
221.00	6	63	15.96	1	0.02	15.91	15.12	1
222.00	13	78	16.16	1	0.03	16.04	15.26	2
223.00	14	54	15.96	1	0.02	15.91	15.12	1
224.00	13	93	16.13	1	0.03	16.04	15.27	2
225.00	14	59	15.96	1	0.02	15.91	15.12	1
226.00	13	88	16.12	1	0.03	16.04	15.26	2
227.00	14	54	15.96	1	0.02	15.91	15.12	1
228.00	13	93	16.14	1	0.03	16.04	15.27	2
229.00	14	54	15.96	1	0.02	15.91	15.12	1
230.00	13	98	16.13	1	0.03	16.05	15.27	2
231.00	14	59	15.96	1	0.02	15.91	15.11	1
232.00	21	88	16.15	1	0.03	16.04	15.27	2
233.00	22	54	15.96	1	0.02	15.91	15.12	1
234.00	21	88	16.08	1	0.03	16.03	15.26	2
235.00	22	49	15.95	1	0.02	15.91	15.13	1
236.00	21	83	16.11	1	0.03	16.04	15.27	2
237.00	22	49	15.97	1	0.02	15.91	15.12	1
238.00	0	78	16.11	1	0.03	16.04	15.27	2
239.00	0	49	16.03	1	0.02	15.98	15.19	1
240.00	4	49	16.03	1	0.02	15.98	15.20	2
241.00	4	49	16.03	1	0.02	15.98	15.19	1
242.00	12	49	16.03	1	0.01	15.98	15.19	1
243.00	20	49	16.03	1	0.02	15.98	15.19	2
244.00	12	49	16.03	1	0.02	15.98	15.17	1

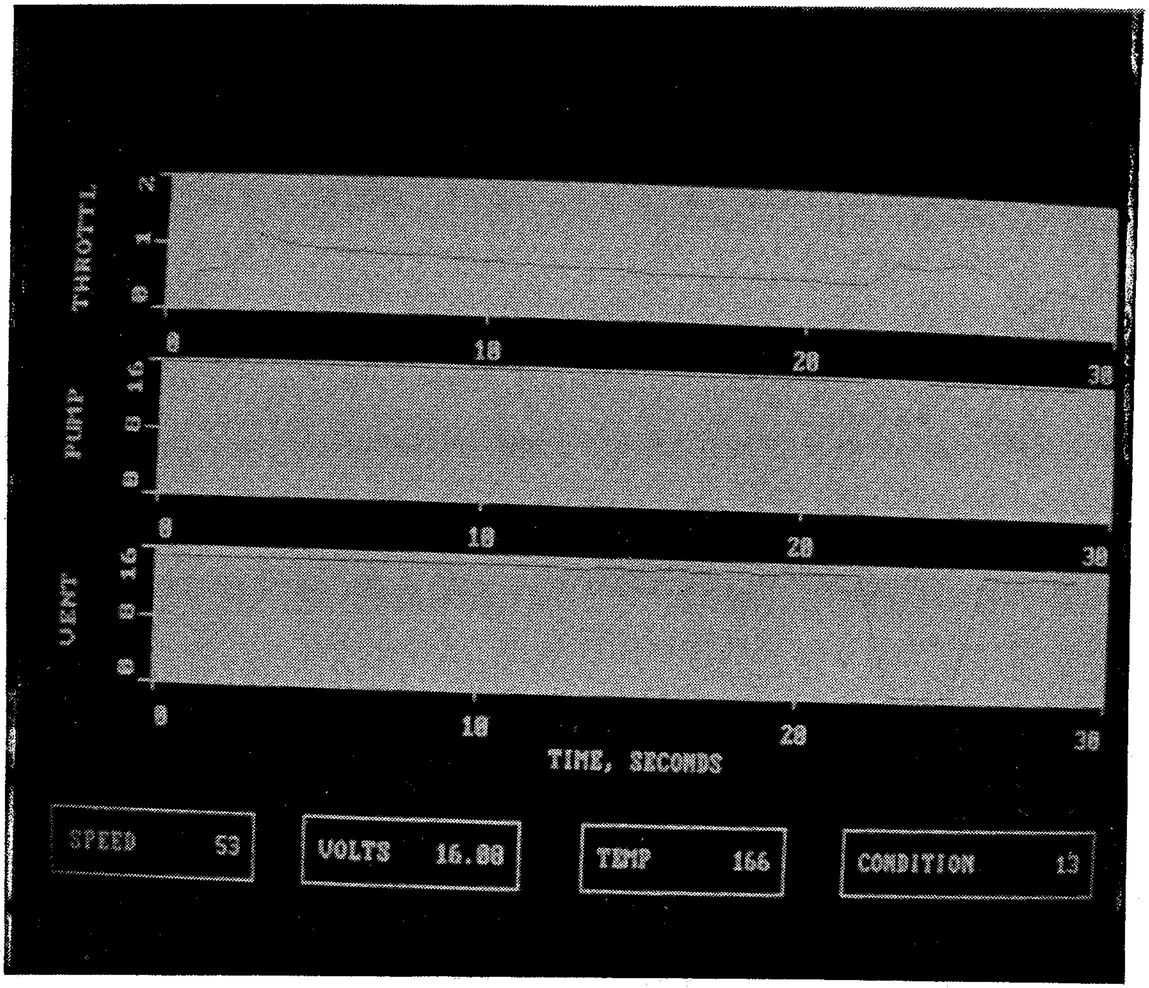
TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
245.00	20	44	16.03	1	0.02	15.98	15.19	2
246.00	12	44	16.03	1	0.02	15.98	15.19	1
247.00	20	44	16.03	1	0.02	15.98	15.20	1
248.00	12	44	16.03	1	0.02	15.98	15.19	2
249.00	20	44	16.03	1	0.02	15.98	15.19	1
250.00	12	44	16.03	1	0.02	15.98	15.20	1
251.00	20	44	16.03	1	0.02	15.98	15.19	2
252.00	5	49	16.03	1	0.02	15.98	15.20	1
253.00	6	44	15.96	1	0.02	15.91	15.12	1
254.00	5	78	16.16	1	0.03	16.04	15.28	2
255.00	6	44	15.96	1	0.02	15.91	15.13	1
256.00	5	83	16.03	1	0.02	15.98	15.19	2
257.00	6	44	15.96	1	0.02	15.91	15.13	1
258.00	5	88	16.15	1	0.03	16.05	15.28	2
259.00	6	49	15.96	1	0.02	15.91	15.12	1
260.00	5	83	16.15	1	0.03	16.05	15.29	2
261.00	6	44	15.96	1	0.02	15.91	15.13	1
262.00	13	78	16.16	1	0.03	16.05	15.29	2
263.00	14	39	15.96	1	0.02	15.91	15.12	1
264.00	13	73	16.14	1	0.03	16.05	15.29	2
265.00	14	44	15.96	1	0.02	15.91	15.12	1
266.00	13	78	16.12	1	0.03	16.05	15.26	2
267.00	14	39	15.96	1	0.02	15.91	15.13	1
268.00	13	73	16.15	1	0.03	16.06	15.26	2
269.00	14	39	15.96	1	0.02	15.91	15.13	1
270.00	13	78	16.14	1	0.03	16.04	15.26	2
271.00	14	39	15.96	1	0.02	15.91	15.12	1
272.00	21	68	16.13	1	0.03	16.05	15.27	2
273.00	22	39	15.96	1	0.02	15.91	15.12	1

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
274.00	21	73	16.11	1	0.03	16.04	15.28	2
275.00	22	44	15.96	1	0.02	15.91	15.12	1
276.00	21	63	16.03	1	0.02	15.98	15.20	2
277.00	22	39	15.96	1	0.02	15.91	15.12	1
278.00	0	73	16.11	1	0.03	16.04	15.28	2
279.00	0	34	16.03	1	0.02	15.98	15.20	1
280.00	4	34	16.03	1	0.02	15.98	15.19	2
281.00	4	34	16.03	1	0.02	15.98	15.19	1
282.00	12	34	16.03	1	0.02	15.98	15.19	1
283.00	20	34	16.03	1	0.02	15.98	15.19	2
284.00	12	34	16.03	1	0.02	15.98	15.19	1
285.00	20	34	16.03	1	0.02	15.98	15.19	1
286.00	12	29	16.03	1	0.02	15.98	15.20	2
287.00	20	34	16.03	1	0.02	15.98	15.19	1
288.00	12	29	16.03	1	0.02	15.98	15.19	2
289.00	20	29	16.03	1	0.02	15.98	15.19	1
290.00	12	29	16.03	1	0.02	15.98	15.19	1
291.00	20	29	16.03	1	0.02	15.98	15.19	2
292.00	5	34	16.03	1	0.02	15.98	15.19	1
293.00	6	29	15.96	1	0.02	15.91	15.12	1
294.00	5	68	16.16	1	0.03	16.06	15.28	2
295.00	6	29	15.96	1	0.02	15.91	15.10	1
296.00	5	73	16.14	1	0.03	16.04	15.30	2
297.00	6	29	15.96	1	0.02	15.90	15.12	1
298.00	5	68	16.16	1	0.03	16.05	15.29	2
299.00	6	24	15.96	1	0.02	15.91	15.12	1
300.00	5	59	16.13	1	0.03	16.04	15.27	2
301.00	6	24	15.96	1	0.02	15.91	15.12	1
302.00	13	63	16.14	1	0.03	16.04	15.26	2

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
303.00	14	24	15.96	1	0.02	15.91	15.12	1
304.00	13	63	16.11	1	0.03	16.05	15.27	2
305.00	14	24	15.96	1	0.02	15.91	15.12	1
306.00	13	58	16.13	1	0.03	16.05	15.25	2
307.00	14	24	15.96	1	0.02	15.91	15.12	1
308.00	13	54	16.15	1	0.03	16.02	15.27	2
309.00	14	24	15.96	1	0.02	15.91	15.12	1
310.00	13	49	16.17	1	0.03	16.05	15.29	2
311.00	14	20	15.96	1	0.02	15.91	15.12	1
312.00	21	44	16.15	1	0.03	16.05	15.26	2
313.00	22	24	15.96	1	0.02	15.91	15.12	1
314.00	21	49	16.10	1	0.03	16.04	15.25	2
315.00	22	20	15.96	1	0.02	15.91	15.12	1
316.00	21	44	16.10	1	0.03	16.04	15.25	2
317.00	22	20	15.96	1	0.02	15.91	15.13	1
318.00	0	39	16.13	1	0.03	16.04	15.25	2
319.00	0	20	16.03	1	0.02	15.98	15.19	1
320.00	4	20	16.03	1	0.02	15.98	15.20	2
321.00	4	20	16.03	1	0.02	15.98	15.19	1
322.00	12	20	16.03	1	0.02	16.03	15.20	2
323.00	20	20	16.03	1	0.02	15.98	15.19	1
324.00	12	20	16.03	1	0.02	15.98	15.19	1
325.00	20	20	16.03	1	0.02	15.98	15.19	2
326.00	12	15	16.03	1	0.02	15.98	15.19	1
327.00	20	20	16.03	1	0.02	15.98	15.20	1
328.00	12	20	16.03	1	0.02	15.98	15.19	2
329.00	20	15	16.03	1	0.02	15.98	15.19	1
330.00	12	15	16.03	1	0.02	15.98	15.19	1
331.00	20	15	16.03	1	0.02	15.98	15.19	2

TIME	TST CODES	TEMP DEG F	SUPPLY VOLTS	SCOPE TRIG	THR INCHES	PUMP VOLTS	VENT VOLTS	SPEED MPH
332.00	5	20	16.03	1	0.02	15.98	15.19	1
333.00	6	15	15.96	1	0.02	15.91	15.12	2
334.00	5	49	16.14	1	0.03	16.04	15.27	1
335.00	6	15	15.96	1	0.02	15.91	15.12	1
336.00	5	54	16.03	1	0.02	15.98	15.19	2
337.00	6	15	15.96	1	0.02	15.91	15.13	1
338.00	5	54	16.16	1	0.03	16.05	15.27	2
339.00	6	15	15.96	1	0.02	15.91	15.13	1
340.00	5	49	16.03	1	0.02	15.98	15.19	2
341.00	6	15	15.96	1	0.02	15.91	15.12	1
342.00	13	34	16.14	1	0.03	16.05	15.28	2
343.00	14	10	15.96	1	0.02	15.91	15.12	1
344.00	13	39	16.13	1	0.03	16.05	15.26	2
345.00	14	19	15.96	1	0.02	15.91	15.12	1
346.00	13	44	16.13	1	0.03	16.04	15.27	2
347.00	14	10	15.97	1	0.02	15.91	15.12	1
348.00	13	49	16.15	1	0.03	16.05	15.25	2
349.00	14	10	15.96	1	0.02	15.90	15.13	1
350.00	13	44	16.11	1	0.03	16.06	15.26	2
351.00	14	10	15.96	1	0.02	15.91	15.13	1
352.00	21	39	16.15	1	0.03	16.04	15.26	2
353.00	22	10	15.96	1	0.02	15.91	15.12	1
354.00	21	49	16.10	1	0.03	16.04	15.26	2
355.00	22	10	15.96	1	0.02	15.91	15.12	1
356.00	21	44	16.11	1	0.03	16.04	15.25	2
357.00	22	5	15.99	1	0.02	15.91	15.12	1
358.00	0	39	16.12	1	0.03	16.04	15.26	3
359.00	0	5	16.03	1	0.02	15.98	15.20	1
360.00	4	5	16.04	1	0.02	15.98	15.19	1

Figure F-3: "Labtech Notebook" display of the screen during the anomaly occurring on the first page of Table F-2. Throttle opening is expressed in inches; the pump and vent measurements are in volts. No current flows through these devices when their controlled terminals are at the supply voltage. This screen photograph was taken at approximately 29 seconds into the run. Because an XT-type computer has difficulty updating its screen fast enough, the information captured in the photograph is partly from the time=28-seconds data sample, and partly from the time=29-seconds sample.



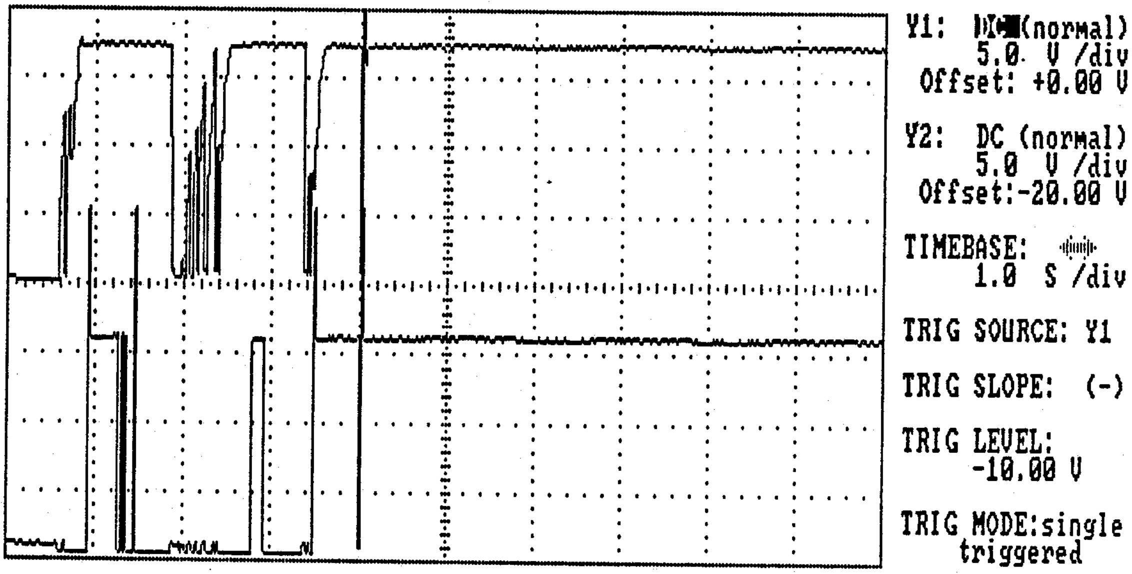
SPEED 53

VOLTS 16.00

TEMP 166

CONDITION 13

Figure F-4: Digital memory oscilloscope recording of the anomaly. Note finer detail due to much higher sampling rate. This recording began at the instant the vacuum pump was energized, i.e. at time=23-seconds, and shows a ten-second sample.



Y1: DC (normal)
5.0 V /div
Offset: +0.00 V

Y2: DC (normal)
5.0 V /div
Offset: -20.00 V

TIMEBASE:
1.0 S /div

TRIG SOURCE: Y1

TRIG SLOPE: (-)

TRIG LEVEL:
-10.00 V

TRIG MODE: single
triggered

APPENDIX G

"Critical Vertical Offset" Measurement Procedure and Data

Background

In the course of test driving various vehicles with high SA-complaint rates, various panel members as well as several other investigators remarked on how the brake pedals of these cars reacted differently from most others. The essence of their comments was that in vehicles with high SA incidence it is easier to open the throttle while applying the brake. It is also easier to mistake the accelerator for the brake because the brake pedal is set lower (closer to the vertical plane of the accelerator) and feels softer (more like the accelerator) than in most other cars. Previous tests conducted at VRTC have suggested that pedal designs in certain vehicles permit unintentional activation of the accelerator while applying the brake. (Ref 38)

Two conditions must be satisfied for a driver to easily open the throttle while simultaneously applying the brake with the same foot: (1) the pedals must be separated laterally somewhat less than the width of the driver's shoe, and (2) the effective vertical range of the brake pedal must be low enough that it is not very much higher than the working range of the accelerator.

With a great deal of force applied, typically 75 pounds or more, any vehicle can be slowed and stopped, even with the throttle wide open. However, for forces in the 20 to 60 pound range, some vehicles, notably those with high SAI complaint rates, continue in motion if the driver's foot overlaps both pedals with the accelerator leading by some small amount.

For the purposes of this study, the distance by which the accelerator-pedal edge of the foot leads the brake-pedal edge is the "vertical offset." The "critical vertical offset" (CVO) is the maximum distance at which the vehicle will remain stationary with a given amount of force applied to the pedals.

While the test-driving experience provides strong intuitive insight into the cause of sudden acceleration accidents, it does not offer the kind of quantitative measures which are the essence of scientific investigation.

Analysis and correlation of the standard measures of pedal location with incidence of SA have failed to show regression coefficients to be as high as should have been expected. Thus is was clear that some new way of measuring pedal characteristics was required.

Objectives

The objectives of this task were: (1) to devise a simple, low-cost means to quantify the differences in pedal design which affect the probability of driver error leading to sudden acceleration, (2) to conduct such measurements on most of the vehicles with much-higher-than-average SA-complaint rates as well as a sample of vehicles with low complaint rates, and (3) to present the results graphically.

Procedures

Lateral Separation: This measure is defined as the distance between the nearest points on the brake and accelerator pedals when the brake is pushed down to the point that it is in the same plane as the accelerator. It can easily be made with a machinist's caliper or combination square. Because of dimensional variability in the rubber and sheet metal parts which affect it, the accuracy in this measure need not be better than one-eighth of an inch.

Critical Vertical Offset: Measuring vertical offset while simultaneously applying substantial force to both pedals requires construction of a special apparatus, illustrated in Figure G-1. This apparatus consists of a base plate of quarter-inch aluminum 4.0 inches high by 7.75 inches wide and drilled with a series of holes along the top and bottom edges through which bolts are inserted and threaded into bands on the underside of the brake pedal so that the plate can be securely clamped to the brake pedal.

Along the right side of the plate are three holes tapped for a half-inch screw. At its lower end, this screw is fitted with a disk 1.9 inches in diameter, which presses against the accelerator. Three holes are provided so that the screw may be positioned as close as possible to the accelerator pivot point. At the top of the screw is a pointer knob to facilitate rapid adjustment.

Near the center of the plate, a strain-gage load cell, Sensotec Model BP, part number 5862, is installed. This device requires a precise 10.00 volt power supply and millivolt meter to read its output, in this case a Fluke model 8050. With this equipment, a pedal force of 20 pounds produces a reading of 2.75 mV, 40 pounds yields 5.50 mV and 60 pounds is equivalent to 8.24 mV. Figure G-2 shows all of this equipment installed in a test vehicle.

In conducting a full test, determinations of whether the vehicle remains stationary, accelerates, or decelerates (if already in motion) were made for 20, 40 and 60 pound forces on the pedals at vertical offset values ranging from 0.5 inches to the amount at which the vehicle remained in motion at all three levels of pedal force. These determinations were recorded on the data sheets, an example of which is presented in Figure G-3.

Tests were made for most vehicles in both "Drive" and "Reverse." For most vehicles, the results were identical in both directions, but in a few instances, the critical offset was slightly smaller in reverse. These instances were noted on the data sheets.

Most of the vehicles tested were owned by the Department of Transportation or by TSC employees. The more expensive Mercedes-Benz and Acura products were provided through the courtesy of their manufacturers and/or dealers.

Figure G-1: Close-up view of apparatus for measuring vertical offset. In the photograph, the device which is clamped to the brake pedal is at the bottom, with the power supply in the center and the readout display at the top.

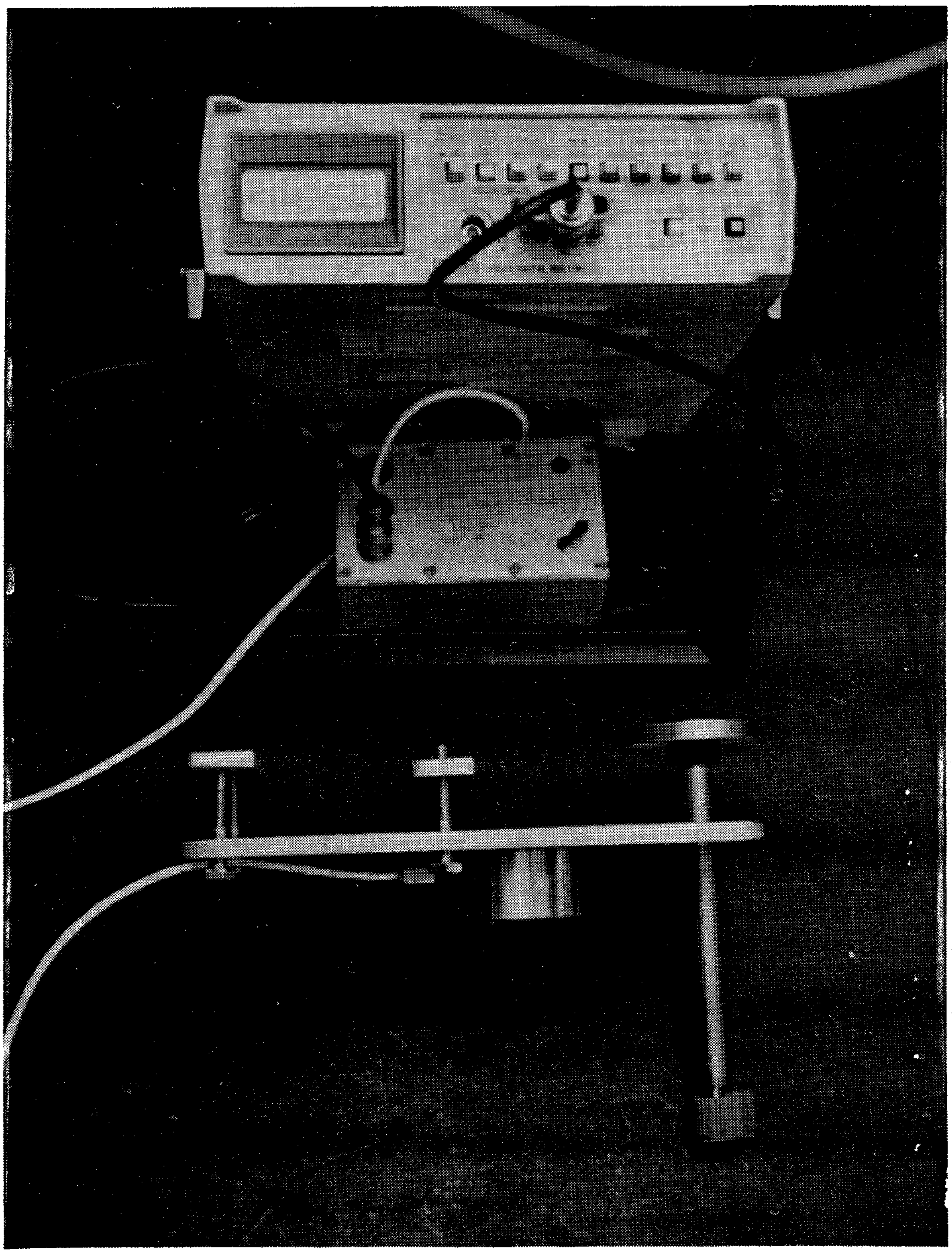


Figure G-2: Photograph of apparatus installed in a test vehicle.

Figure G-3: Example data sheet for pedal separation and CVO test.

MAKE/MODEL: Plymouth Voyager YEAR: 1984

OWNER: DOT / TSC PHONE:

LATERAL SEPARATION: 3 1/4 INCHES

APPLIED FORCE:	20#	40#	60#
OFFSET (inches)			
0.5	stationary	—	—
0.75	〃	—	—
1.0	〃	—	—
1.25	〃	—	—
1.5	〃	—	—
1.75	moves	slows	stops
2.0	〃	〃	moves very slowly
2.25	〃	accelorates	slows
2.5			

Results The following table shows the measured pedal separations and CVO (both expressed in inches) at various levels of applied pedal force for seventeen vehicles:

Vehicle	Lateral Separation	Critical Vertical Offset		
		20#	40#	60#
Audi 5000, 82	2.13	*	*	1.5
Audi 5000, 84	2.13	.5	.5	2.0
Honda Accord	2.25	.5	*	.75
Mercedes-Benz 420 SEL	2.38	.5	*	*
Honda Civic	2.38	*	*	.5
SAAB 900	2.38	1.0	1.0	1.25
Volvo 240	2.38	1.5	1.75	2.0
Oldsmobile Cutlass	2.38	1.25	1.75	2.0
Acura Legend	2.63	*	*	*
Acura Integra	2.63	*	*	*
Mercedes-Benz 300E	2.63	.5	*	*
Nissan 280ZX	2.63	.5	.5	.75
Toyota Corolla	2.63	.5	1.75	2.0
Mercury Grand Marquis	3.13	.75	1.0	1.75
Plymouth Voyager, 84	3.25	1.5	1.5	1.75
Toyota Camry	3.25	.75	2.25	2.25
Plymouth Voyager, 86	3.25	1.75	2.52	.75

*** denotes that vehicle moved at the minimum offset permitted by the test apparatus, which was 0.5 inches. Hence the true CVO is less than 0.5 inches.**

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

DOT-TSC-NHTSA-88-4
Final Report

September, 1988

Appendix H:
Study of Mechanical and Driver - Related Systems of the Audi 5000 Capable of Producing Uncontrolled Sudden Acceleration Incidents

Gary Carr
John Pollard
Don Sussman
Robert Walter
Herbert Weinstock

U.S. Department of Transportation
Research and Special Programs
Administration
Transportation Systems Center
Cambridge, MA 02142

Prepared for

National Highway Traffic Safety Administration
Office of Defects Investigation
400 7th Street, SW
Washington, DC 20590

Technical Report Documentation Page

1. Report No.	2 Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
STUDY OF MECHANICAL AND DRIVER-RELATED SYSTEMS OF THE AUDI 5000 CAPABLE OF PRODUCING UNCONTROLLED SUDDEN ACCELERATION INCIDENTS

5. Report Date
December 1988

6. Performing Organization Code
DTS-45

7. Author(s) Robert Walter, Gary Carr,
Herbert Weinstock, Don Sussman,
John Pollard

8. Performing Organization Report No.
DOT-TSC-NHTSA-88-4

9. Performing Organization Name and Address
Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge, MA 02142

10. Work Unit No. (TRAIS)
HS910/S9024

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Highway Traffic Safety Administration
Office of Defects Investigation
400 7th Street, SW
Washington, DC 20590

13. Type of Report and Period Covered
Final Report
Jan. 1987 - Dec. 1988

14. Sponsoring Agency Code
NEF10

15. Supplementary Notes

The rate of Sudden Acceleration Incident (SAI) complaints received by NHTSA for the Audi 5000 has been unusually high. SAI complaints characteristically report unanticipated full-power acceleration which can not be controlled by braking.

The report discusses the possible contributions of the subject vehicle and the driver to the complaint rate. It reviews prior investigations of the Audi 5000 and describes new engineering and statistical analyses conducted to gain insights into the possible causes of SAI. The report discusses the engine system, transmission, brakes, controls, and driver demographics. The possible contribution of driver pedal misapplication was examined in terms of driving environment, driver population, type of driving and driving experience.

Among the principal conclusions were: 1) Some versions of Audi idle-stabilization system were prone to defects which resulted in excessive idle speeds and brief unanticipated accelerations of up to 0.3g. These accelerations could not be the sole cause of SAIs, but might have triggered some SAIs by startling the driver. 2) The pedal and seating arrangements of the Audi are significantly different from larger domestic cars. These differences may contribute to a higher incidence of pedal misapplication, especially for relatively unfamiliar drivers. 3) Brake failures are very unlikely and would be detectable after the event if they occurred.

17. Key Words
Sudden Acceleration Incident, Audi 5000
Braking, Idle-stabilizer, Pedal
Misapplication

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH
THE NATIONAL TECHNICAL INFORMATION SERVICE,
SPRINGFIELD VIRGINIA 22161

19. Security Classif. (of this report)	20 Security Classif (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

Form DOT F1700.7 (8-72) Reproduction of completed page authorized

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 (NEF-10). The work was performed at TSC by the Structures and Dynamics Division (DTS-76) and the Operator Performance and Safety Analysis Division (DTS-45).

This document was essentially completed in September, 1988. Since its detailed engineering analyses of the Audi complement the broader scope of the "Examination of Sudden Acceleration" study, TSC chose to publish the two reports together, with the Audi report as an appendix to the general report. The findings described in Chapter 7 and the summary of this appendix do not fully reflect the understandings of the significance of pedal design gained during the final quarter of 1988. The reader is referred to the general report for the more complete discussion of these matters.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

1. INTRODUCTION AND SUMMARY

1.1 BACKGROUND

The National Highway Traffic Safety Administration's (NHTSA) Office of Defects Investigation (ODI) is currently investigating owner complaints about the Audi 5000. These complaints allege that the vehicle produces sudden, uncontrollable accelerations known as "sudden acceleration incidents" (SAIs). For SAIs resulting in accidents, driver reports provided to ODI typically indicate that while the vehicle was at rest the driver shifted the transmission from park to reverse or drive, the vehicle suddenly accelerated, and the brakes could not bring the car under control. The incidents reported frequently occurred during the first year of ownership. After an incident, inspection of the vehicle by NHTSA usually revealed no failure or malfunction of any vehicle system.

Although reports of SAIs have been received for a variety of automobile makes and models, ODI has found that the Audi 5000 has been associated with the greatest rate of such complaints. According to ODI, for the 1978 to 1986 model years (as of October 18, 1988), drivers attributed 556 accidents per 100,000 Audi 5000 vehicles sold in the U.S. to sudden acceleration. The highest comparable rate for other makes and models was 28 per 100,000 vehicles.

Initial investigations by both the U.S. importer, Volkswagen of America (VWOA), and ODI could find no consistent mechanical failures that could cause this phenomena. VWOA has claimed that these incidents were the result of driver error, and that drivers reporting SAIs had inadvertently depressed the accelerator pedal instead of the brake pedal.

In the period 1982 to 1987, VWOA conducted four recall campaigns germane to SAI reports:

- In April 1982, a recall was conducted to modify the accelerator pedal to prevent interference with the floormats.
- In September 1983, a plate was attached to the brake pedal to elevate it relative to the accelerator pedal.
- In July 1986, Audi began replacing some idle-stabilizer valves in conjunction with an unrelated recall.
- During September 1986, as part of a service action, Audi began installing automatic shift locks (ASL) in 1984-86 vehicles.
- In January 1987, a formal voluntary recall was initiated to install ASL in all model years, to check for idle speed problems, and to replace certain stabilizer valves
- In October 1987, VWOA announced a recall of the idle-stabilizer system for the 1984 and 1985 Audi 5000s. (VWOA contends that this recall is not related to SAI problems.)

As part of its continuing investigation, ODI requested that the U.S. Department of Transportation, Transportation Systems Center (TSC) perform an independent analysis of the Audi's electronic, electromechanical, and mechanical systems; driver compartment configuration (particularly the control dimensions and forces); and driver population characteristics to identify any possible associations between these factors and SAIs. This report details the results of TSC's analysis.

1.2 ORGANIZATION OF TSC STUDY

This study included: (1) an examination and fault tree (detailed failure mode) analysis of the vehicle's major mechanical, electronic, and electromechanical subsystems to determine the conditions under which these subsystems could be responsible for the incidents; (2) an analysis of the dimensions and design of the Audi driver compartment to determine if the features of the compartment and driving controls might increase the probability of pedal misapplication resulting in an SAI; and (3) an analysis of the characteristics of Audi drivers to determine if they are more likely than the drivers of other vehicles to be involved in or exposed to situations where an SAI could occur.

Figure 1-1 depicts the potential causes and results of an SAI. As is indicated, the incident must be initiated by an increase in engine power. This increase may be caused either by a system malfunction (a failure in one or more of the engine systems listed in Figure 1-1), or by the driver inadvertently depressing the accelerator. In the former case, loss of vehicle control can occur if the brakes fail, or if the driver inadvertently depresses the accelerator rather than the brake pedal or otherwise fails to apply the brakes. If the initiating cause is pedal misapplication, loss of control can occur if the driver continues to depress the accelerator pedal, believing it to be the brake. This report summarizes the material gathered by TSC with regard to the features of the vehicle that could potentially lead to system malfunction and/or pedal misapplication.

An analysis of the Audi's power train (Section 2) indicated that the following systems are the most likely potential sources of a malfunction leading to the initiation of an SAI:

- the idle-stabilizer system
- the cruise control system
- the transmission linkage

Information on the design of these systems and the results of tests conducted are presented in Sections 3, 4, and 5.

In an SAI, failure to stop the vehicle must involve either a failure by the driver to apply the brakes or a malfunction of the braking system. The braking system is discussed in Section 6.

If the initiation of the incident and subsequent loss of control are not due to a vehicle system malfunction, they must then be due to pedal misapplication. The accuracy and timeliness with which the driver controls the vehicle are strongly influenced by both the design and dimensions of the operating controls and the driver's familiarity with the vehicle. Data comparing these aspects of the Audi 5000 with those of other cars in the U.S. fleet, as well as information on the anthropometry and demographic characteristics of Audi 5000 drivers, are presented in Section 7.

1.3 METHODOLOGY

In the study, TSC used the following logic:

- The SAI must be initiated by a significant increase in engine power. This can be caused either by a failure in one or more engine systems or by a pedal misapplication.
- If the initiating cause is a system malfunction, loss of vehicle control can occur through either brake failure or pedal misapplication.
- If the initiating cause is pedal misapplication, loss of control can occur if the driver is not aware of it and continues to depress the accelerator pedal.
- Driving a vehicle with an unfamiliar or unusual driving compartment configuration can increase the probability of pedal misapplication.
- If the cause of an SAI is an electromechanical or mechanical failure, physical evidence of such a failure should be detectable in a post-SAI examination of the vehicle.

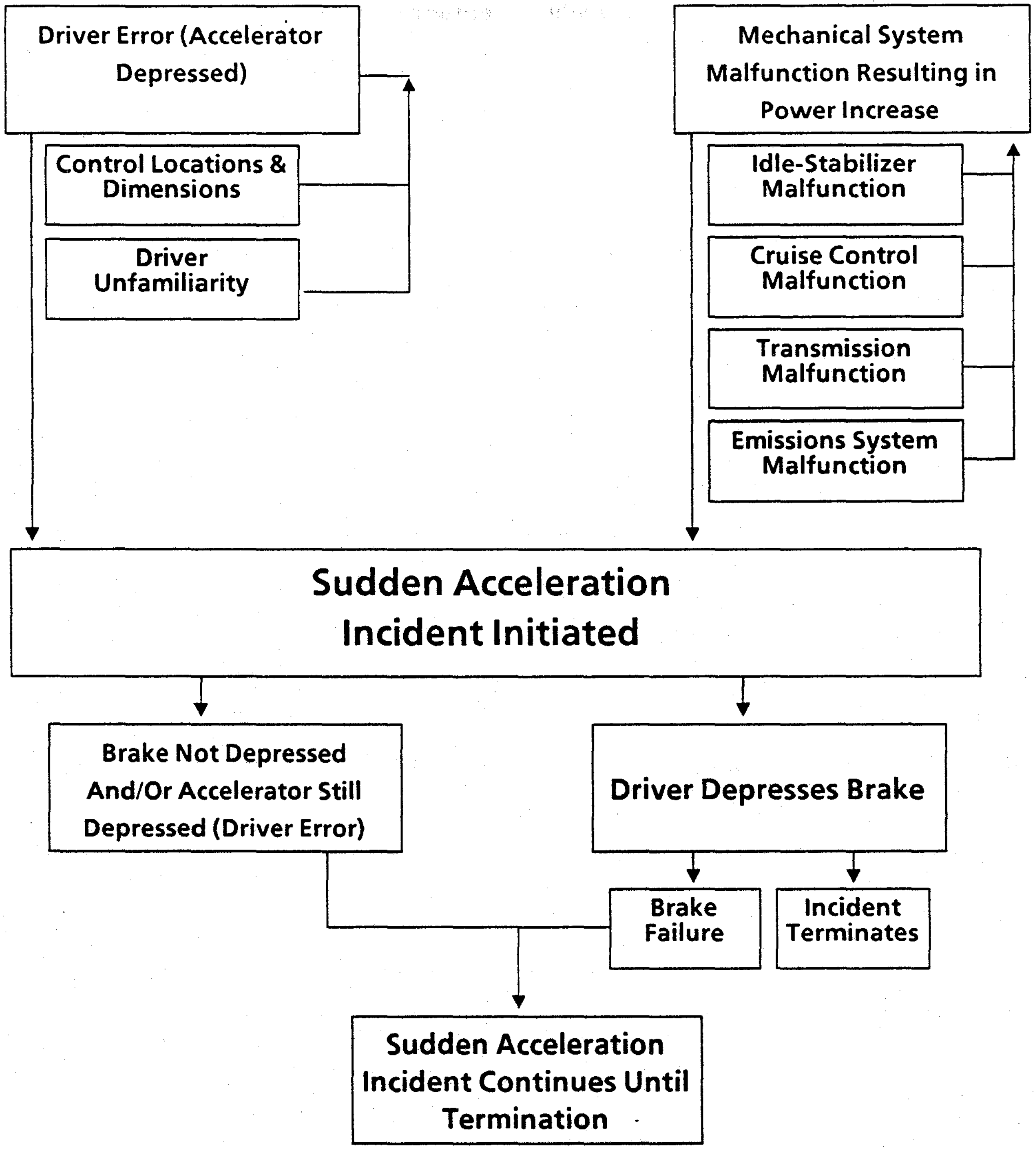


FIGURE 1-1. SUDDEN ACCELERATION INCIDENT SCENARIO

- If an intermittent electronic failure is the cause of the SAI, post-incident detection may be much more difficult but the failure mode should be reproducible either through in-vehicle or laboratory bench tests.

1.3.1 Potential Failure Modes - Power Train System

Significant increases in engine power (sufficient to produce an SAI) can be produced only if both air and fuel flows to the engine are increased while maintaining a fuel–air mixture which provides relatively complete fuel combustion. In the Audi 5000, when metered airflow increases, the fuel management system increases fuel flow, resulting in an immediate increase in engine power.

TSC's analysis indicated that in the case of the Audi 5000, this increase in engine power could be possible only through:driver movement of the throttlemechanical movement of the throttle plate (caused by malfunction of the accelerator linkage or transmission "feedback" linkage to the accelerator linkage)

- malfunction of the cruise control

- malfunction of the idle-stabilizer system

- some other malfunction which increases airflow to the fuel management system, e.g., air leakage

Malfunctions of the engine ignition and timing system, emissions control system, and engine vacuum systems could not produce the power involved in an SAI.

Throttle System – After the accelerator pedal is depressed, the throttle linkage could conceivably "stick," causing the pedal to hold its position. This could be caused by binding in the system or some mechanical interference with the linkage or the pedal. The first SAI-related recall by VWOA involved installation of a shield on the accelerator pedal to prevent jamming against the floormat. While accelerator pedal "sticking" has been reported to ODI by owners, these incidents do not fit the spontaneous acceleration scenario. However, they could fit the scenario if the pedal were stuck before the vehicle had been started.

Transmission Activation of Throttle – In the 1978 through 1983 Audi 5000, the transmission could conceivably activate the linkage and throttle plate in a shift from drive into neutral, reverse, or park. In these models, the throttle plate could be opened if an unbalanced pressure of at least 117 psi were applied to the kickdown valve. An SAI due to transmission activation of the throttle would require multiple failures, would be irreversible, and would be easily detected after the fact. No evidence of such failures was found in vehicles exhibiting SAIs by TSC or ODI investigators.

Cruise Control System – Multiple simultaneous failures in this system would be required to produce SAIs from a stopped or low-speed condition (the SAI reported by the great majority of involved drivers). Both a gear-selector safety switch (powered only in drive or second gear) and an operator's switch would have to be closed, and an electronic control unit (designed to function only above 30 mph) must fail to initiate an SAI. In addition to these failures, a simultaneous mechanical failure in the vacuum breaker attached to the brake pedal would be required to prevent the driver from defeating the cruise control by braking. No evidence of such failures was found in vehicles exhibiting SAIs by TSC or ODI investigators.

Self-activation of the cruise control's "resume" function at speeds above 30 mph with the cruise control switch on has been observed in one instance by TSC, and other drivers have reported such incidents to NHTSA and VWOA. Such incidents do not, however, resemble the typical SAI.

Idle-Stabilizer System – Audi 5000 (1984 and thereafter) incorporates an idle-stabilizer system which regulates engine speed in response to the demands of engine load. The system is composed of an electronic control unit and an electromechanical air valve. Two types of valves are used in the vehicles of interest: a rotary valve and a linear valve.

When the electronic control unit in this system malfunctions, excess current may flow through the idle-stabilizer valve, causing it to open fully and thereby producing an immediate increase in engine power. Tests reported by VWOA (October 1986) have indicated that the idle-stabilizer system alone can accelerate the Audi 5000 at an initial rate of 0.3 g, which is similar in magnitude to an emergency stop in a subway car. With the valve fully open, the vehicle can reach speeds of 20 to 25 mph in reverse or forward gears in approximately 10 seconds, and eventually reach speeds of 40 to 50 mph in forward gears.

Intermittent malfunctions of the electronic control unit were observed and recorded by TSC in this study and have been reported by Transport Canada (personal communication). Such failures, because of their intermittent nature, would most likely not be detected during normal Audi-specified testing of the unit, or in post-accident NHTSA investigations.

In the rotary-valve version of the idle stabilizer, problems with intermittent failures of the commutator contacts have been reported. Such defects may cause engine surging directly and may also cause oscillations leading to premature spring failure. Once the spring has broken, idle stabilization is apt to become more erratic.

1.3.2 Potential Failure Modes - Braking System

The reports of SAIs indicate that once the increase in engine power began, the driver could not stop the vehicle with the brakes, implying brake failure. TSC and NHTSA tests indicate that the Audi 5000 brakes, when operating properly at the low road speeds typical of the SAI, will hold or stop the car even under full throttle.

Temporary Failure of the Hydraulic Power-Brake Assist – The hydraulic power boost used in 1984 and later models hold sufficient pressurized fluid for 15 to 20 brake applications after engine shutdown. If the Audi engine speed is above 1000 RPM (as is characteristic of SAI reports), rapid pumping of the brake pedal cannot deplete the reservoir. Even with depletion of the reservoir the brakes still operate, but require four to five times the normal force from the driver to stop the car (not beyond the capability of the great majority of drivers). A malfunction resulting in failure of the hydraulic power-brake assist with the engine running would be detectable in post-SAI investigations. No evidence of such malfunctions was found in vehicles exhibiting SAIs by TSC or ODI investigators.

Complete Brake Failure – This can be caused only by loss of hydraulic fluid pressure from both sides of the dual hydraulic brake systems incorporated in all of the Audi 5000s with reported SAIs. Such complete, simultaneous failures are irreversible and would be easily detected after an incident. No evidence of such failures was found in vehicles exhibiting SAIs by TSC or ODI investigators.

1.3.3 Potential Failure Modes - Pedal Misapplication

VWOA has claimed that the SAIs reported for the Audi 5000 were a result of pedal misapplication. TSC analyzed the interior dimensions of the Audi 5000, the dimensions and actuation forces of its controls, and the characteristics of its driver population to identify factors which could induce pedal misapplication and cause or contribute to the disproportionate number of SAIs reported for the vehicle.

Driving Environment – TSC performed a statistical study comparing the Audi 5000's interior seating and pedal arrangements to hundreds of other vehicle models in the U.S. fleet for critical driver-related dimensions. The study revealed statistically significant differences for 20 dimensions. Among the dimensions which were significantly different were seat height; knee angle; lateral steering-wheel position; knee clearance; brake pedal force, size, height, and travel; and accelerator pedal size and height.

Prior research by TSC (Hoxie 1984) and NHTSA (Perel 1983) have revealed that driver unfamiliarity with a vehicle can markedly increase the likelihood of an accident.

From the statistical comparison of vehicle interior dimensions and the studies of driver familiarity, it can be conjectured that drivers who have extensive experience with other vehicles but are new to the Audi may make a disproportionate number of pedal misapplication early in their use of the vehicle.

TSC's analysis of NHTSA's National Accident Sampling System indicates that 34 percent of all drivers involved in accidents nationwide have less than 6 months of experience with the vehicle involved. By way of comparison for Audi SAIs, 44 percent of the drivers had less than 6 months' experience with the vehicle.

Driver/Driving Characteristics – A major source of statistical variation in automobile accident rates is the demographic characteristics of the driver. TSC found that middle-aged and older drivers involved in Audi 5000 SAIs were overrepresented when compared with drivers in all accidents nationwide. (This is especially true for middle-aged and older female drivers.) Such individuals are similarly overrepresented as owners and drivers of the Audi 5000.

In addition, the Nationwide Personal Transportation Study shows that female drivers take more trips which require frequent starts and stops, conditions which increase the opportunity for SAIs.

1.4 SUMMARY OF FINDINGS

Based on its analysis of the Audi 5000, its components, and NHTSA and VWOA data, TSC reached the following conclusions:

- The Audi 5000 has mechanical and electronic failure modes that could induce engine surging and produce unexpected increases in engine power. In particular, failures in the idle-stabilizer system used in 1984 to 1986 vehicles have been observed which produce surges typical of some SAIs and could potentially initiate such incidents. Because of their intermittent nature, these idle-stabilizer system failures would most likely not be detected during normal Audi-specified testing of the unit, or in post-accident NHTSA investigations.
- The complete brake failures reported in the Audi 5000 SAIs are very unlikely events which, had they occurred, would have been detectable after an incident or accident. Only one such incident is known to have occurred. In that instance, brake hoses were severed.

- The seating, pedal arrangements, and pedal forces of the Audi 5000 are significantly different from the standard domestic vehicles, increasing the likelihood of confusion of the brake and accelerator pedal for drivers new to the vehicle.
- The apparent overrepresentation in the Audi 5000 driver population of individuals whose driving patterns involve frequent "starts" may have increased the opportunity for SAIs.

In summation, TSC was not able to identify any combination of malfunctions in the Audi 5000 which would simultaneously produce sudden acceleration and brake failure without leaving readily obvious evidence. Failures in the idle-stabilizer system, and to a much lesser extent the cruise control system, were identified which are capable of initiating an SAI without leaving evidence detectable under normal test procedures.

Furthermore, failures in the braking system which would preclude the driver from stopping the car were not identified. TSC also determined that the dimensions of the Audi 5000 driver's compartment and the forces and dimensions of its controls are significantly different than other vehicles in the U.S. fleet, increasing the possibility of pedal misapplication in individuals unfamiliar with the vehicle. It can therefore be concluded that once unwanted acceleration has begun, pedal misapplication resulting from panic, confusion, or perhaps unfamiliarity with the Audi 5000 contributes to the severity of the incident.

2. IDENTIFICATION OF POTENTIAL MECHANICAL FAILURES FOR SUDDEN ACCELERATION INCIDENTS

2.1 BACKGROUND

The typical reported scenario for sudden acceleration is that the driver enters an already warmed-up car (i.e., engine at operating temperature), starts the car, and moves the shift lever into drive or reverse. The car then rapidly accelerates in the direction of the gear selected. Although the driver immediately applies the brake, the vehicle does not stop. The SAI is stopped when the ignition switch is turned off, the transmission is shifted to park or neutral, or the vehicle strikes an object. Inspection of the vehicle after the incident typically shows no mechanical malfunction. Usually the car has less than 10,000 miles on the odometer. An equal number of incidents occur in drive and reverse.

For sudden acceleration to occur, the engine of the vehicle must develop power. To study the possible mechanical causes of increased engine power, a fault tree analysis was performed (see Figure 2-1). The fault tree shows that for the engine to develop sufficient power, the flow of both air and fuel must increase. Fuel and airflow increases with an open throttle plate, an open idle-stabilizer valve, or a malfunction that allows an increased air and fuel mixture to enter the intake manifold. The systems capable of changing the engine performance by moving the throttle plate include the cruise control system, the transmission and kickdown valve, and the throttle linkage system. The systems capable of changing the engine performance with the throttle plate closed (idle position) include the ignition system, the fuel-injection system, the exhaust gas recirculation system, the positive crankcase ventilation system, and the idle-stabilization system. These systems and components are reviewed in the following sections. Particular emphasis is placed on identifying systems and components capable of malfunctioning in an intermittent or self-correcting manner.

2.2 CLOSED THROTTLE PLATE

2.2.1 Idle-Stabilization System

The idle-stabilization system adjusts the amount of metered air that bypasses the throttle plate at idle conditions. The valve operates continuously when the throttle plate is fully closed. It responds to different engine loading conditions to maintain a constant, preset idle speed. If this valve were to malfunction, the vehicle could accelerate in forward or reverse. TSC calculated that a fully open idle-stabilizer valve on a 1986 Audi 5000S produces an initial acceleration of 0.3 g and would reach a final speed of 33 mph in reverse gear or 40 to 45 mph in forward gear. This vehicle acceleration may alarm the driver. Since the idle-stabilization system has these capabilities, a detailed discussion of its operation and possible failure modes is presented in Section 3.

In Sections 2.2.2 through 2.2.6, changes in engine performance (brake torque) are estimated from test data on typical gasoline engines (Taylor 1966).

2.2.2 Ignition System

The ignition system, which is computer-controlled, supplies a 32,000 V spark to each cylinder at the proper time. A change in ignition system timing could increase the engine performance at idle. At idle, the timing of the spark is usually retarded 15 to 20° from the MBT (Maximum Torque) timing position. As shown in Figure 2-2, the brake mean effective pressure (ratio of brake torque to volumetric displacement) changes about 18 percent from the MBT timing position to the 20° retarded position. If the timing were changed to the MBT position from the 20° retarded position, the indicated

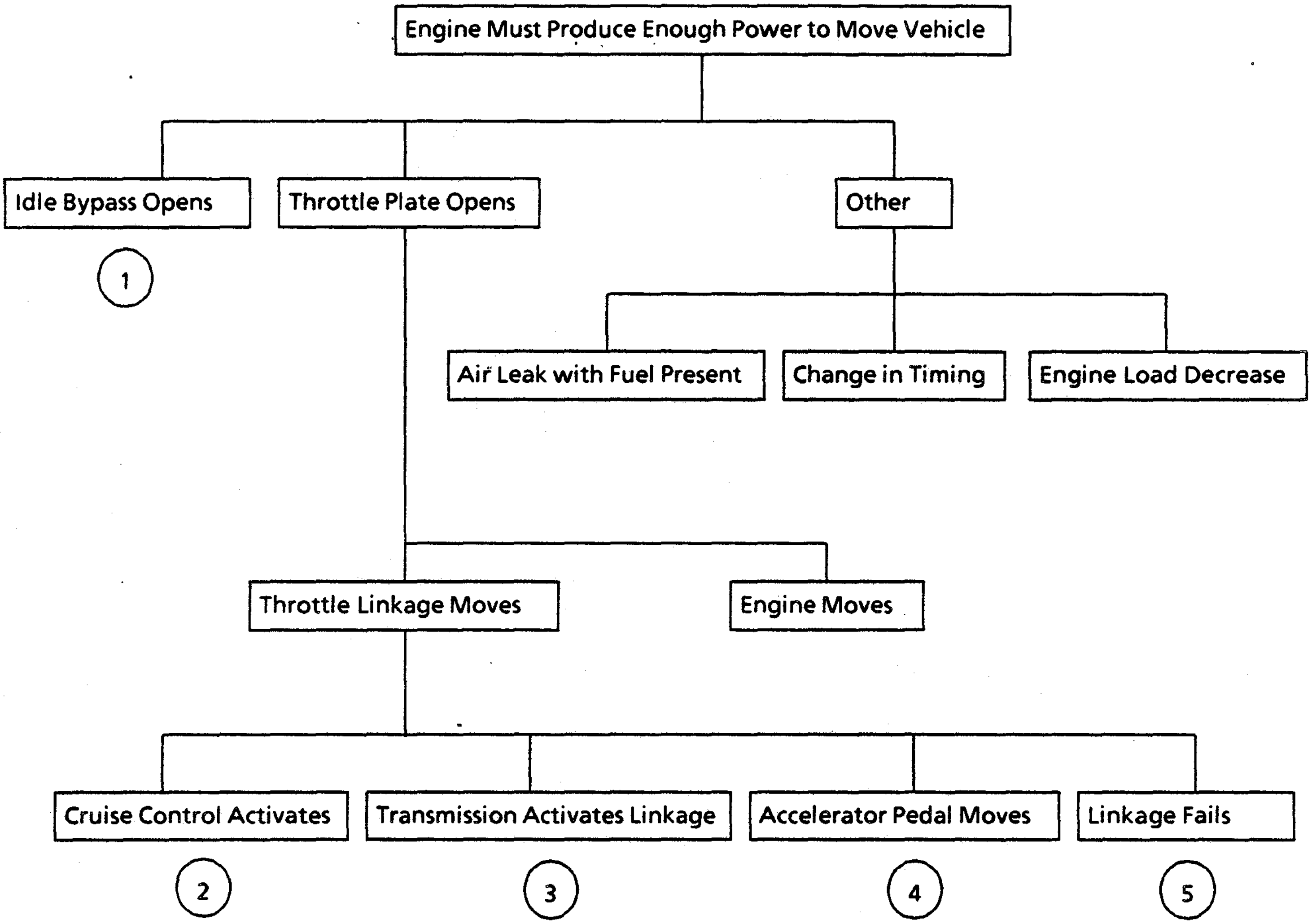


FIGURE 2-1. FAULT TREE ANALYSIS

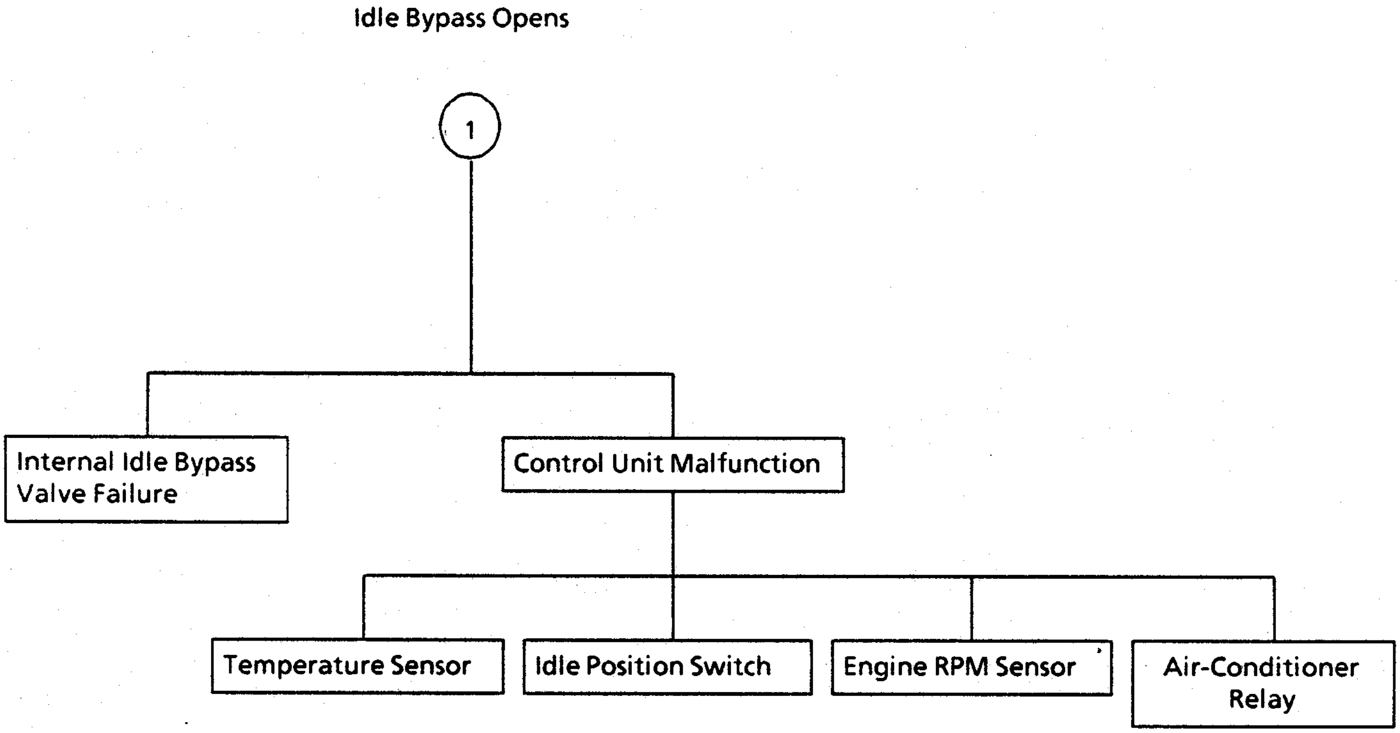
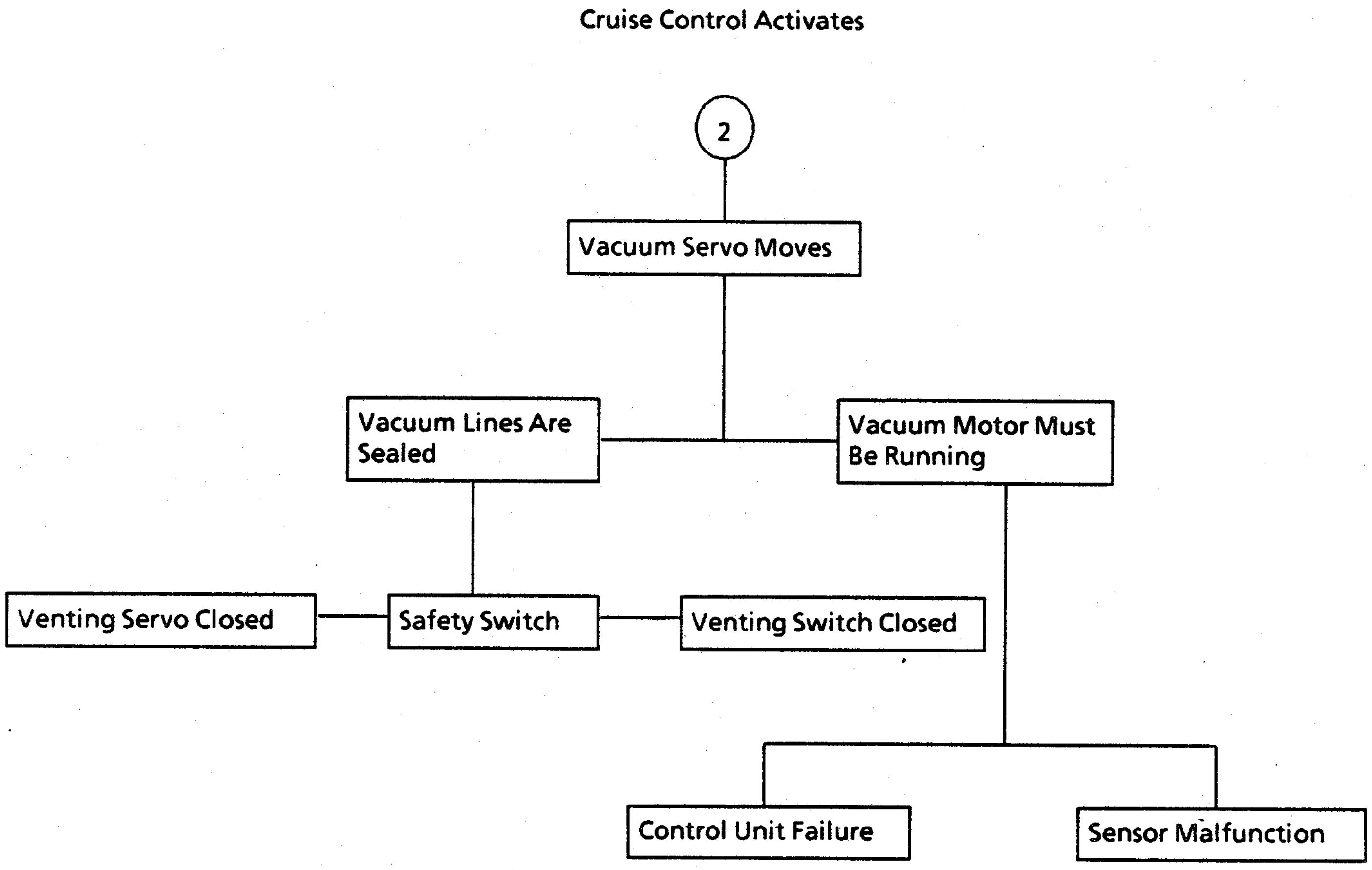
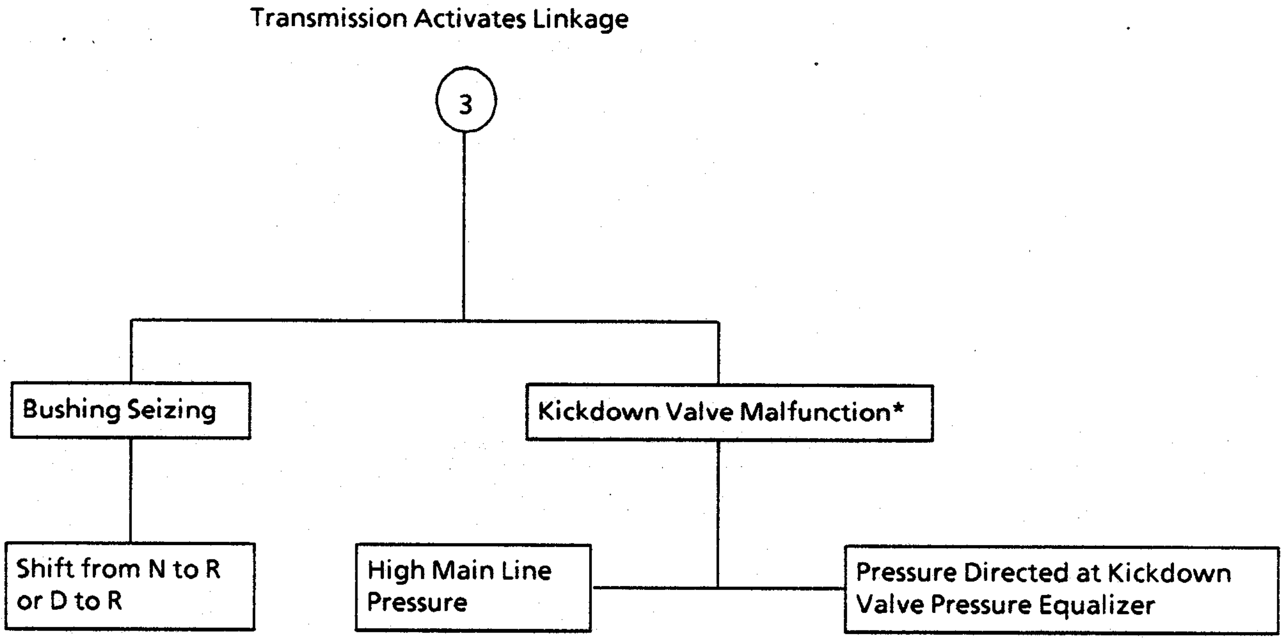


FIGURE 2-1. FAULT TREE ANALYSIS (continued)



Cruise Control Activates

FIGURE 2-1. FAULT TREE ANALYSIS (continued)



*Does not apply to transmissions from 1984 to 1986

FIGURE 2-1. FAULT TREE ANALYSIS (continued)

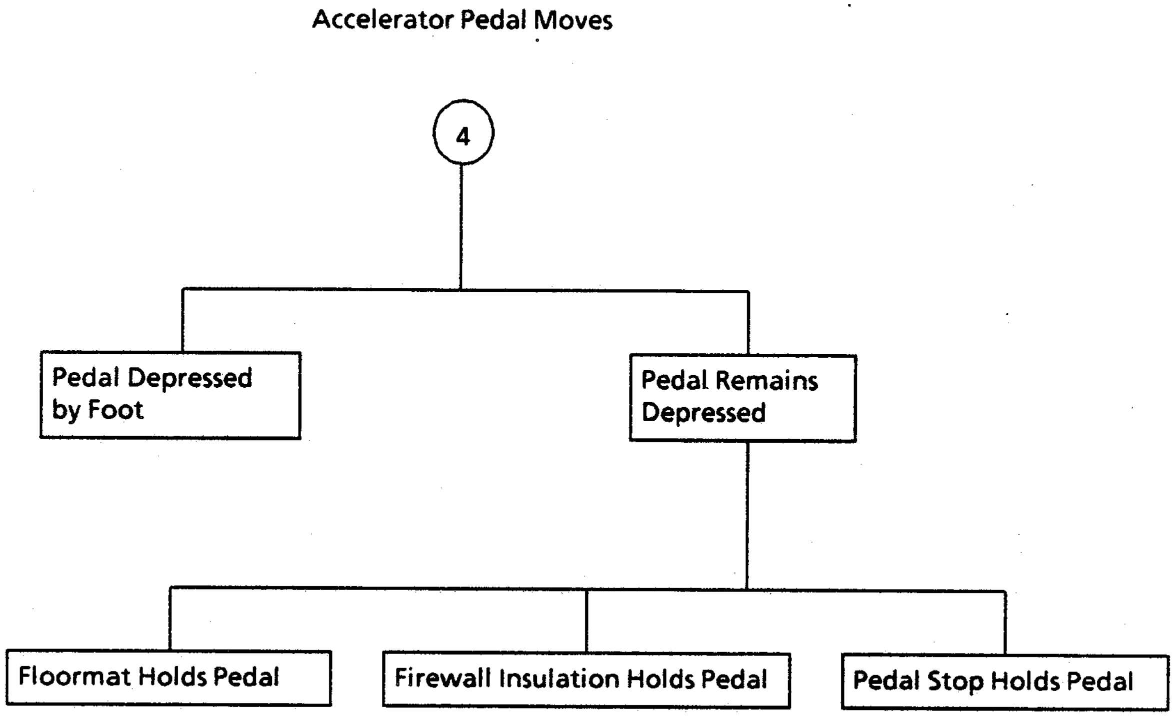


FIGURE 2-1. FAULT TREE ANALYSIS (continued)

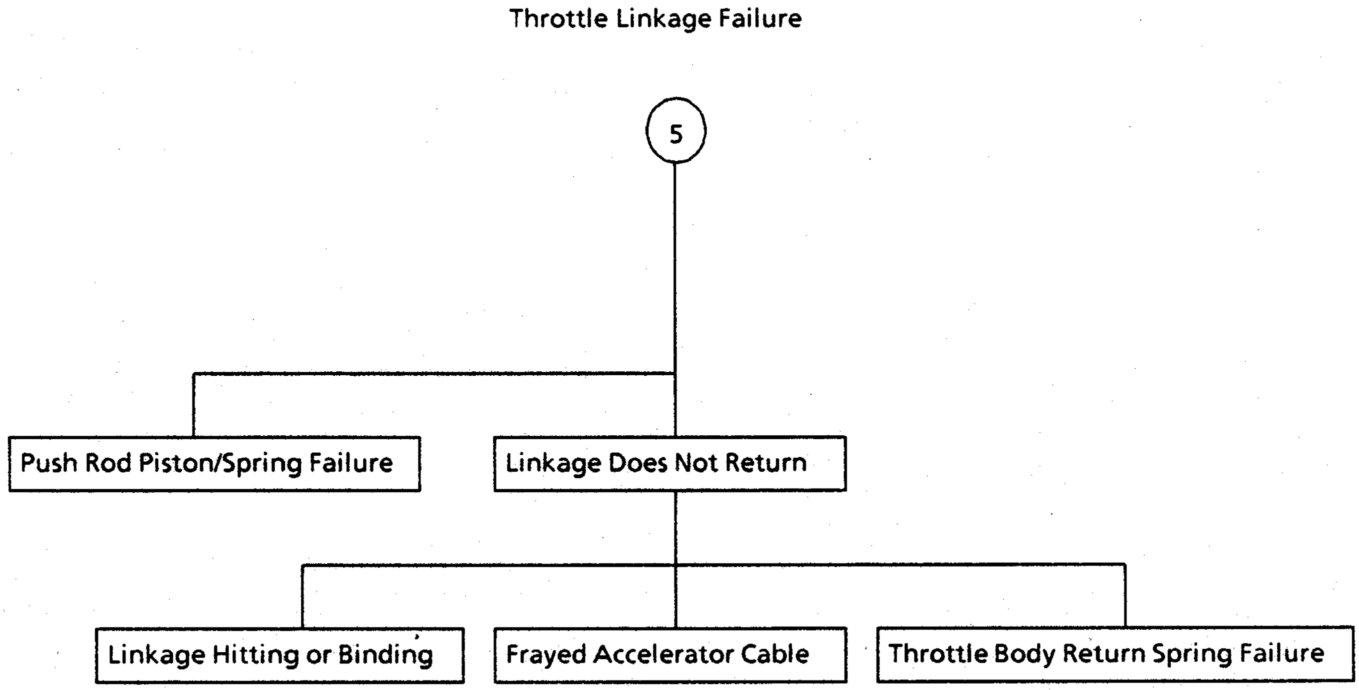
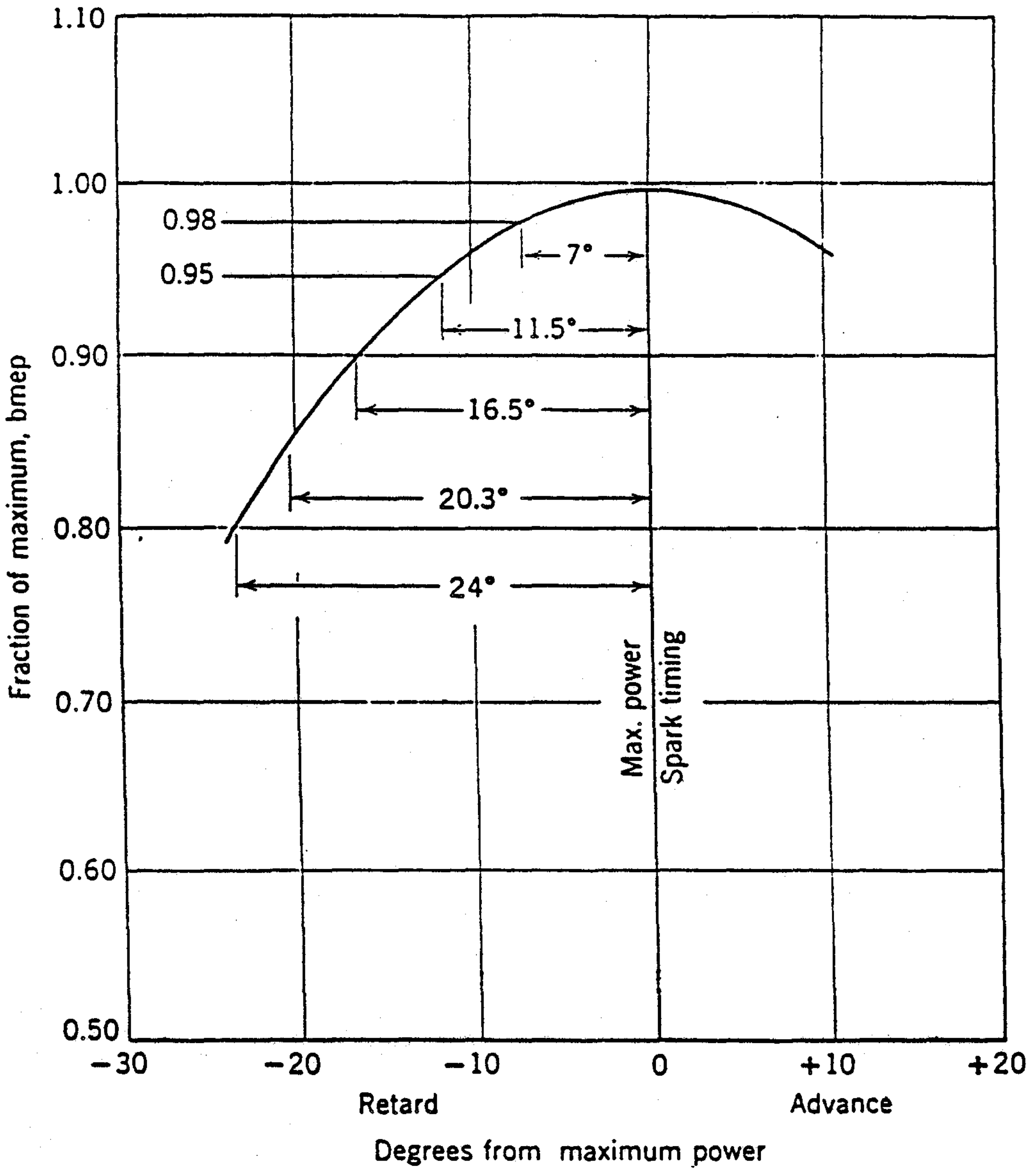


FIGURE 2-1. FAULT TREE ANALYSIS (continued)



SOURCE: Taylor 1966, 443.

FIGURE 2-2. SPARK TIMING CORRELATION FOR ALL SPEEDS AND LOADS torque at idle could increase up to 18 percent. Based on this, TSC estimates the change in brake torque would have an upper bound of 3.2 lb-ft for the Audi five-cylinder engine. The resultant change in the vehicle acceleration is not significant enough to cause an SAI.

2.2.3 Fuel-Injection System

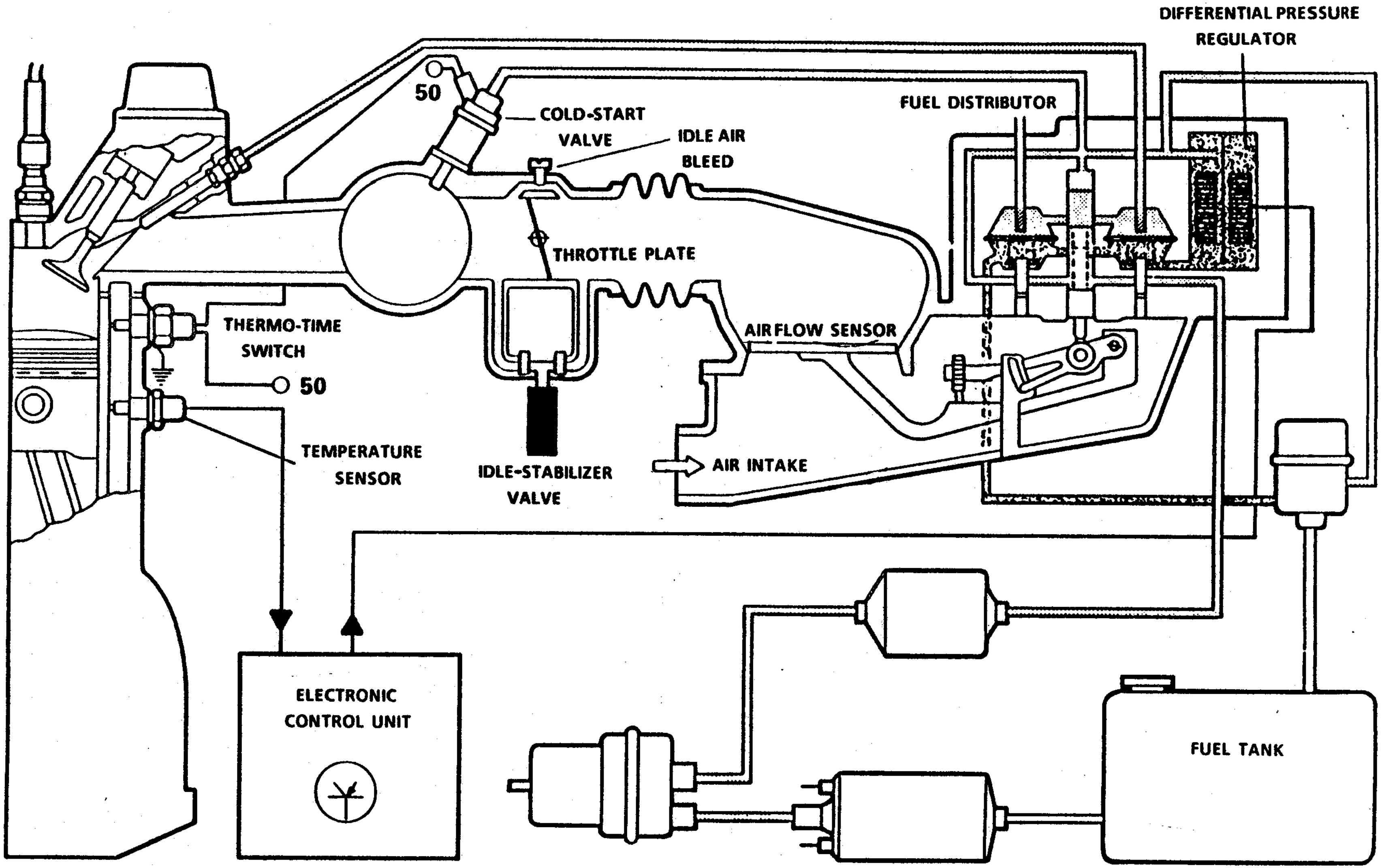
The fuel-injection system used in the Audi 5000 from 1978 through 1986 model years is called the continuous-injection system (CIS). This system continuously injects fuel to all cylinders in quantities proportional to the amount of air drawn in by the engine. There are two methods for the fuel-injection system to deliver the appropriate fuel–air mixture to the engine. The primary method is to directly measure the amount of air entering the intake manifold with an airflow sensor plate mounted before the throttle plate (see Figure 2-3). The secondary method is through control based on the oxygen level in the exhaust gases. An oxygen sensor measures the amount of oxygen in the exhaust gases while the fuel-injection computer control unit monitors the sensor to determine the amount of additional fuel to allow into the fuel injectors. This part of the fuel-injection system does the "fine" fuel metering while the airflow sensor does the "coarse" fuel metering. The flow of air into the engine is controlled by the throttle plate position, idle stabilizer, and the idle air bleed. These air regulators allow "metered" air (air that is measured by the sensor plate) into the intake manifold. At idle, the fuel–air mixture is maintained around stoichiometry (fuel–air equivalence ratio or $Fr = 1.0$) as shown in Figure 2-4. If the air regulators are properly operating and a fuel system malfunction caused the fuel–air mixture to become richer ($Fr > 1.0$), the maximum torque increase would be about 5 percent of idle torque. If the fuel–air equivalence ratio increased to greater than 1.2, engine performance would decrease, and eventually the engine would stall. If the fuel–air mixture was leaned out ($Fr < 1.0$), the engine performance would also decrease until the engine stalled. The maximum change in torque is on the order of 1 to 2 lb-ft, which is not significant enough to cause sudden acceleration.

2.2.4 Exhaust Gas Recirculation Valve

The exhaust gas recirculation (EGR) valve is generally mounted on vehicles that do not use the oxygen sensor and three-way catalyst, i.e., vehicles equipped to be used in Canada or pre-1984 Audis. The EGR valve is mounted between the exhaust manifold and the intake manifold. This valve allows exhaust gases into the intake manifold to cool combustion temperatures and reduce exhaust emissions. For the valve to operate, the engine must be fully warmed up and the throttle plate must be in a part-throttle position. An open EGR valve with the throttle plate fully closed (at idle) could only cause a decrease in engine performance. The inert exhaust gases entering the intake charge decrease the amount of oxygen present to burn the fuel. As a result, the flame speeds in the combustion chamber would be low and the overall combustion would be poor. The result of poor combustion is a very rough idle and possible engine stalling. A failed EGR system could not cause sudden acceleration.

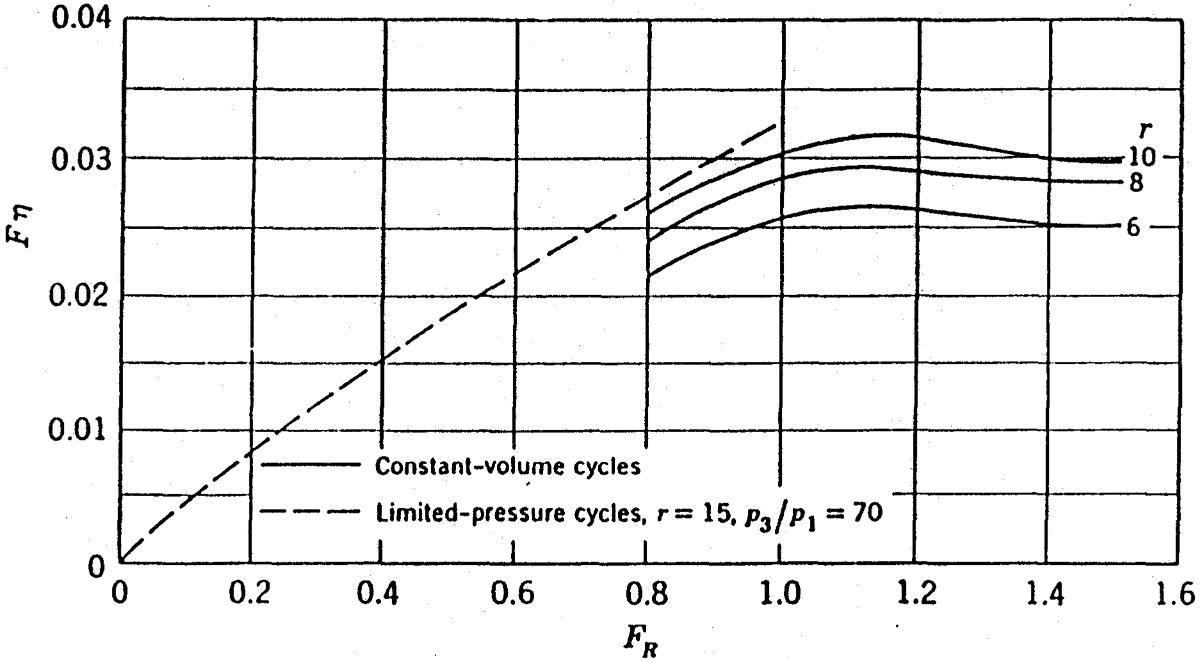
2.2.5 Positive Crankcase Ventilation System

The positive crankcase ventilation system for the Audi 5000 consists of a restrictor mounted in a hose from the crankcase of the engine to the air intake. This allows exhaust gases and any unburned fuel–air mixture that has escaped past the cylinders to reenter the air intake charge. If the positive crankcase ventilation system failed by eliminating the restrictor, the effect would be the same as leaning out the mixture; the engine would decrease in performance and eventually stall. If the restrictor became clogged, the fuel–air mixture could become richer ($Fr > 1.0$). The maximum increase in idle torque would be on the order of 5 percent (less than 0.1 g initial vehicle acceleration), which is not significant enough to cause sudden acceleration.



SOURCE: CIS-Electronic Fuel Injection Training Manual 1986, 18.

FIGURE 2-3. FUEL SYSTEM DIAGRAM FOR THE AUDI FIVE-CYLINDER ENGINE



Fr ≡ EQUIVALENCE RATIO: Fr = 1.0 STOICHIOMETRY
Fr < 1.0 LEAN
Fr > 1.0 RICH
Fη ≡ (FUEL-AIR RATIO) x (INDICATED THERMAL EFFICIENCY)

SOURCE: Taylor 1966, 437.

FIGURE 2-4. PRODUCT Fη FOR FUEL-AIR CYCLES

2.2.6 Vacuum System

When the engine is under idle conditions, the vacuum in the intake manifold is at its highest level. At idle, a leaking gasket or a broken vacuum line would allow unmetered air to enter the intake manifold. Since the air is not measured by the airflow sensor, the fuel–air mixture would lean out ($Fr < 1.0$). The oxygen sensor in the exhaust manifold would sense this change in the fuel–air mixture. The fuel-injection control unit adjusts the differential pressure valve which readjusts the fuel–air mixture by providing more fuel. A small air leak could produce a limited power increase, the magnitude of which cannot be precisely determined because the adjusting limits of the differential pressure valve are not known. If the air leak were large enough, the control unit could not adjust the fuel to overcome the excess air. Engine performance would then decrease and the engine would eventually stall. In any event, significant air leaks would remain detectable and would not correct themselves.

2.3 MOVING THROTTLE PLATE

2.3.1 Linkage

Throttle plate movement allows air measured by the sensor into the intake manifold. The fuel mixture for this air would be adjusted to the proper ratio. The performance of the engine would then be limited only by the amount of air that was allowed into the engine (that is, the throttle plate position). There are three methods for the throttle plate to be opened. The first is by activation of the cruise control (see Section 4). The second method is by linkage attached to the transmission's throttle valve. This method is only applicable to pre-1984 Audi 5000s, since the linkage connection was then changed from a mechanical link to a butted joint. The butted joint cannot transmit a tension force from the transmission kickdown valve to the throttle linkage (see Section 5). The throttle plate can also be opened by the operator depressing the accelerator pedal. If the accelerator pedal were depressed and remained depressed, the fault could be due to broken linkage, sticking pivots, faulty return springs, or some other mechanical interference such as floor carpets.

2.3.2 Cruise Control

The cruise control system has a vacuum servo that is directly connected to the throttle plate. If a vacuum were applied to this servo and maintained, the throttle plate could be moved to a fully open position. The cruise control system has many safeguards to prevent this from happening. For the system to apply a vacuum to the servo, two simultaneous component failures must occur. Refer to Section 4 for a detailed analysis of possible failure modes.

2.3.3 Transmission

Because there is a direct link between the engine's throttle valve and the transmission's kickdown valve which could possibly open the throttle, TSC studied the linkage as a possible factor in SAIs. The transmission can only affect operation in this way in 1978 through 1983 Audis, as later models have been reconfigured. Further, should a failure occur, it would not be reversible and would be found in post-incident investigations. Section 5 discusses the linkage between the engine and the kickdown valve of the transmissions, as well as automatic transmission operation, kickdown valve operation, and potential failure modes.

2.4 BRAKE SYSTEM

Once sudden acceleration has occurred, the brakes should be able to stop the car. A typical driver complaint is that the brake pedal was depressed but the brakes did not control the vehicle. The brake system could fail to operate for two possible reasons: The driver may react incorrectly to the incident (for example, by delaying brake application or not depressing the pedal at all); or the brake system may malfunction. Driver-related issues are described in Section 7, while Section 6 focuses on the brake system itself, particularly the hydraulic power assist. The power-assist mechanism reduces the force the driver must apply to stop the vehicle. To produce 0.3 g of deceleration, a brake-pedal force of 22.5 lb-f would be required with the assist working. However, if the assist does not function, the required pedal force increases to 90 lb-f. The hydraulic assist is capable of temporarily malfunctioning, but only under the conditions not characteristic of SAIs. Even without power assist, the great majority of drivers would be able to prevent an SAI with the brakes. This is further explained in Section 6.

3. IDLE-STABILIZATION SYSTEM

3.1 INTRODUCTION

The idle bypass system is found in 1984 and later Audi 5000 models with fuel injection. (Prior models used an electrically heated air regulating valve for the cold-start function.) An idle-stabilization system maintains a constant idle speed while adjusting to different load conditions. As shown in Figure 3-1, TSC's study was based on two possible situations:

1. The valve itself is defective (broken spring, sticking bearings, intermittent commutator).

2. The electronic control unit (ECU) operates incorrectly.

3.2 SYSTEM DESCRIPTION

The idle stabilizer is a linear-actuated valve on the 1984 Audi 5000S and 1984 to 1986 Audi 5000 Turbo models, and is a rotational-actuated valve on the 1985 to 1987 Audi 5000S models. A schematic of the stabilizer valve and control system is shown in Figure 3-2. Incoming air is regulated by the valve, which is electrically operated. Adjusting the flow of "metered" air causes the engine to change power and speed.

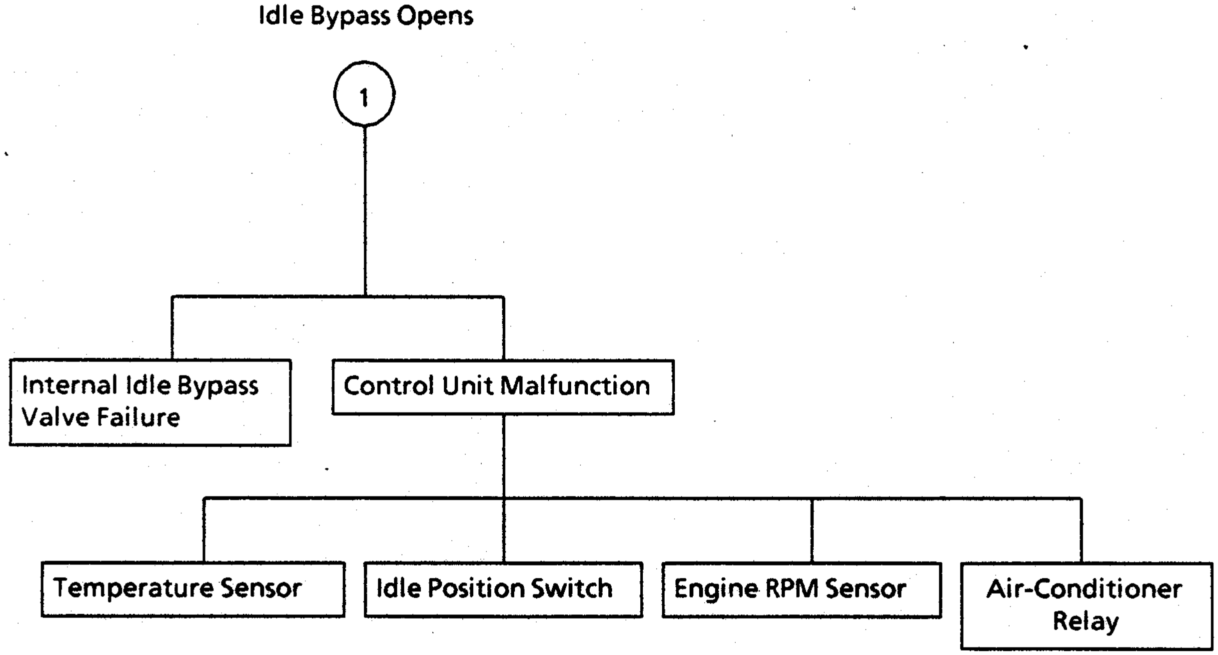
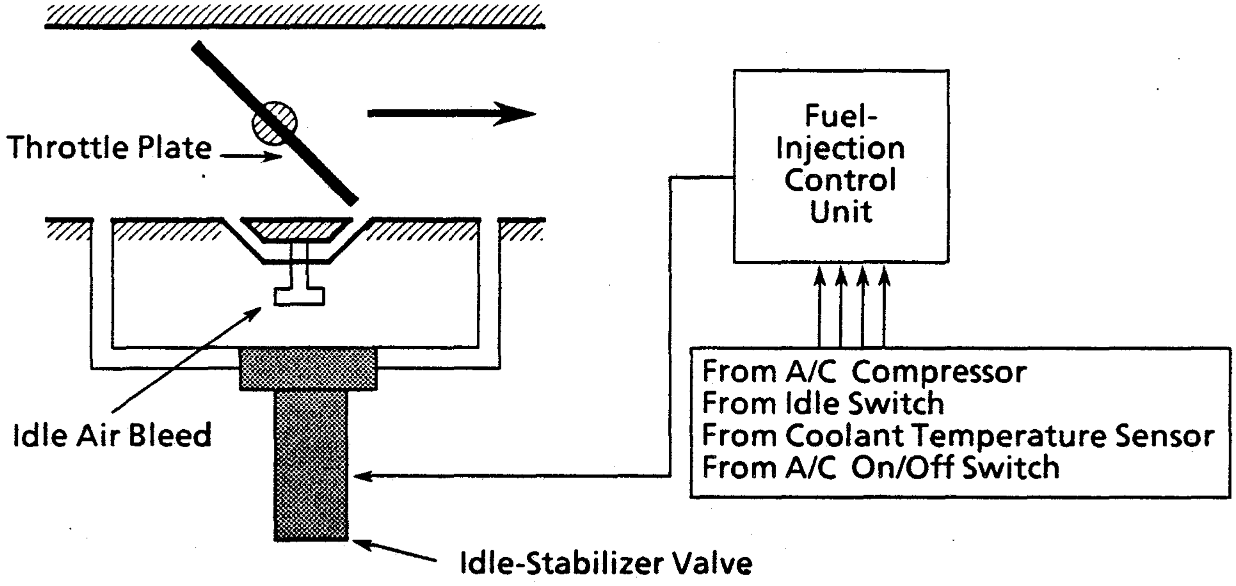


FIGURE 3-1. FAULT TREE ANALYSIS: IDLE BYPASS SYSTEM



SOURCE: CIS-Electronic Fuel Injection Service Training Manual 1986, 20.

FIGURE 3-2. IDLE-STABILIZER VALVE LOCATION AND CONTROLS

The fuel-injection control unit controls the idle-stabilizer valve on the 1985 through 1987 model years while the 1984 system has a separate control unit specifically for the stabilization system. The control unit monitors the engine RPM, engine coolant temperature, throttle plate state, air-conditioner on/off switch, and air-conditioner clutch operation. Based upon the measurements taken, the control unit chooses the appropriate engine idle RPM from three preset options:

Engine coolant temperature < 40° C	1000 RPM
Engine coolant temperature > 40° C	800 RPM
Engine coolant temperature > 40° C and air conditioner on	920 RPM

These preset values vary slightly in different versions of the system. The ECU is designed to limit its maximum output current whenever the throttle plate is open. After the proper RPM is selected, the control unit commands the idle-stabilizer valve to increase or decrease the airflow to change the engine RPM.

3.3 VEHICLE PERFORMANCE WITH IDLE-STABILIZER VALVE FULLY OPEN

In response to requests from NHTSA, VWOA provided plots of engine torque versus engine speed for the range of throttle plate opening angles for the Audi 5000S engine. VWOA also conducted tests of the vehicle and engine performance with the transmission in gear and the idle-stabilizer valve fully open. These tests were also made with the throttle plate open to an angle of 20°. Table 3-1 lists the engine speed developed at the start of the tests with the brakes fully applied and the transmission in gear. Measurements corresponding to this condition were also made at TSC on a 1986 5000S Turbo vehicle.

Based on this data, it is estimated that fully opening the idle-stabilizer valve corresponds to a 13.5° throttle plate opening for the 1984 5000S, a 21.3° throttle plate opening for the 1986 5000S, and a 14.3° throttle plate opening for the 1986 Audi 5000S Turbo (see Figure 3-3).

Calculations were performed by TSC using the engine torque versus speed characteristics to estimate the acceleration and velocity time histories of a 1986 Audi 5000S with the throttle plate open to an angle of 20°. This result is compared to the Audi test results in Figure 3-4, where the idle-stabilizer valve is fully open and the transmission is in reverse gear.

It can be seen that the calculations generally agree with the measurements for vehicle speeds between 4 and 19 mph. The smaller starting acceleration measurement is believed to be the result of delays in fully releasing the brake. The difference at speeds above 19 mph resulted from the test being terminated before the final speed was achieved. TSC calculations indicate that if the test had not been terminated, a sudden opening of the idle-stabilizer valve would result in an initial acceleration of 0.3 g's with the vehicle in reverse gear with no brakes applied, achieving a velocity of 24 mph in approximately 10 seconds. In these 10 seconds the vehicle would travel about 230 ft (see Figure 3-5). As shown in Figure 3-6, the final speed of the vehicle achieved in 30 to 40 seconds would be between 28 and 33 mph.

TABLE 3-1. TEST RESULTS

VWOA Tests*

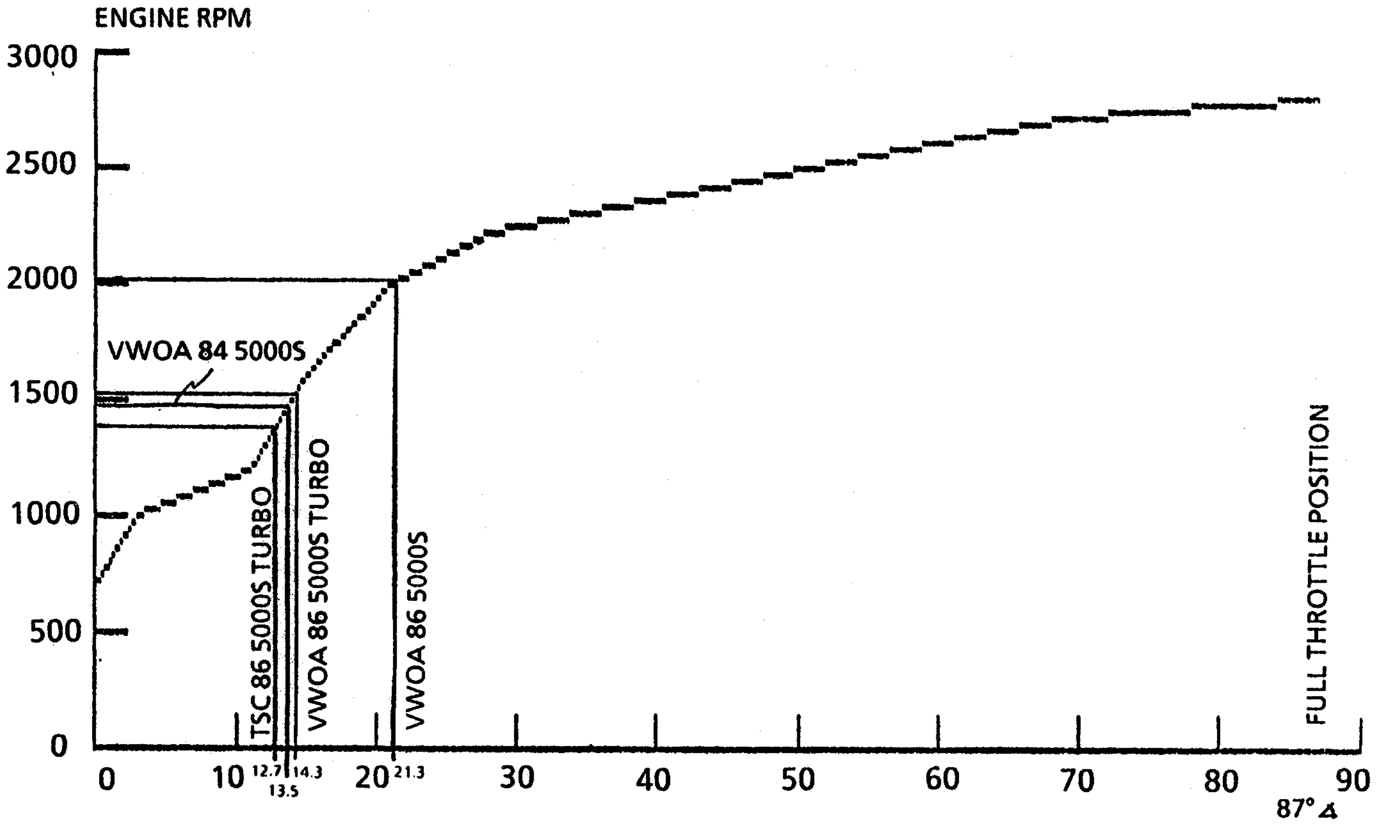
Engine RPM**	Vehicle Model
1493	1984 Audi 5000S (rotary valve, fully open)
1897	1984 Audi 5000S (20° throttle angle)
2013	1986 Audi 5000S (rotary valve, fully open)
2128	1986 Audi 5000S (20° throttle angle)
1536	1986 Audi 5000S Turbo (linear valve, fully open)
2127	1986 Audi 5000S Turbo (20° throttle angle)

TSC Tests

Engine RPM**	Vehicle Model
1400	1986 Audi 5000S Turbo (linear valve, fully open)
1400	1986 Audi 5000S Turbo (rotary valve, fully open)

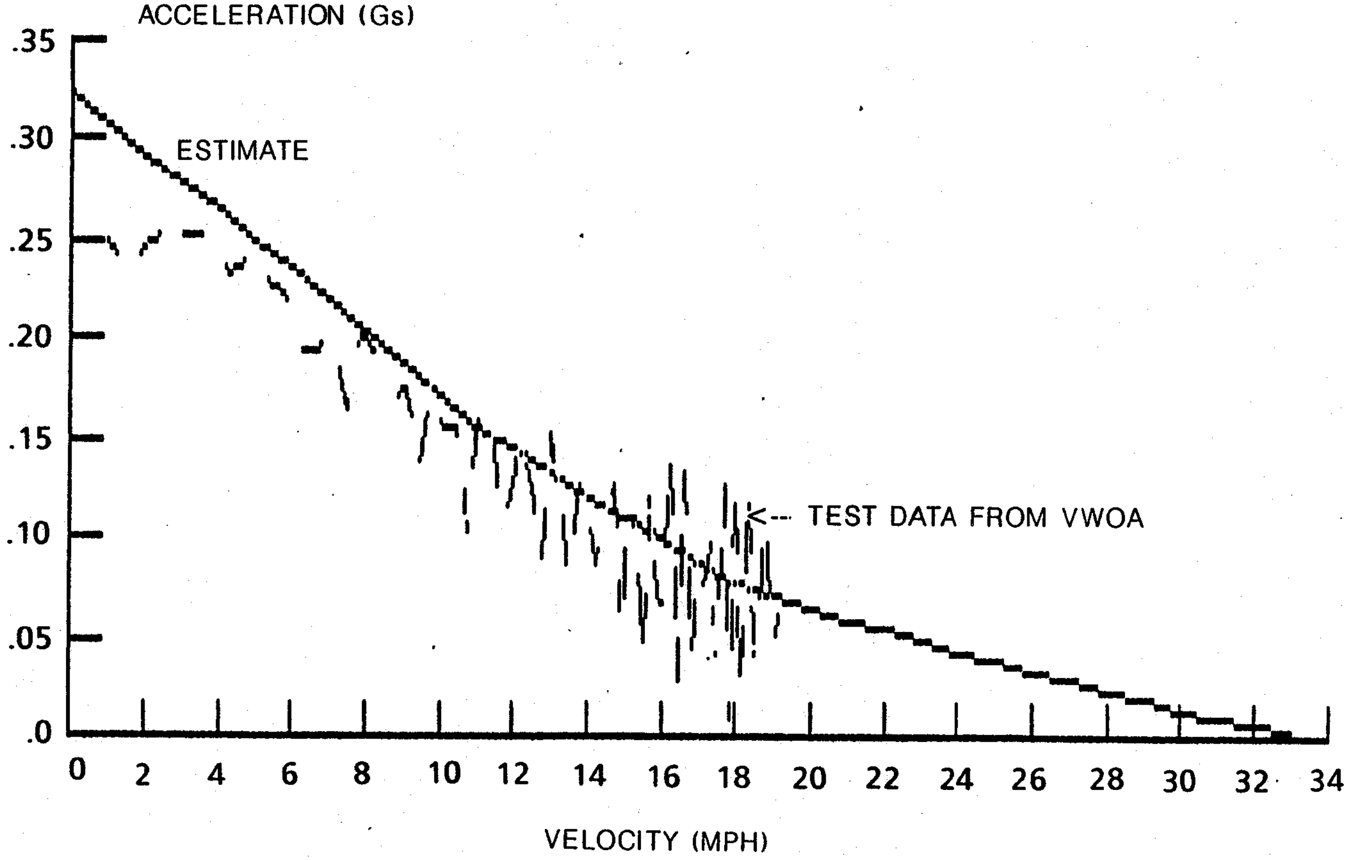
* Test results received by TSC through ODI from VWOA

** RPM measurement with brake fully applied and vehicle in reverse gear



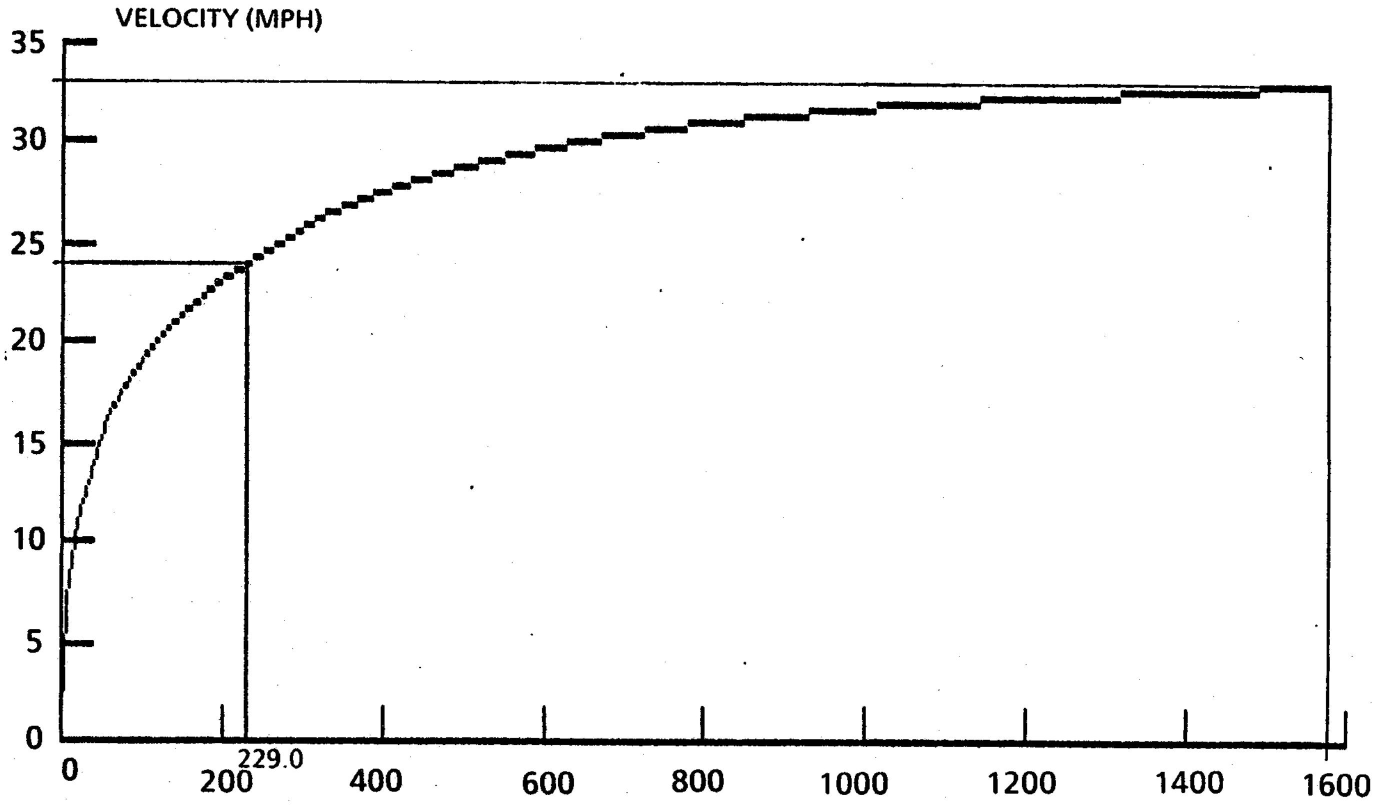
SOURCE: Based on TSC and VWOA test data.

FIGURE 3-3. ENGINE RPM VERSUS THROTTLE ANGLE IN REVERSE GEAR WITH BRAKES APPLIED



SOURCE: Based on TSC calculations and VWOA test data.

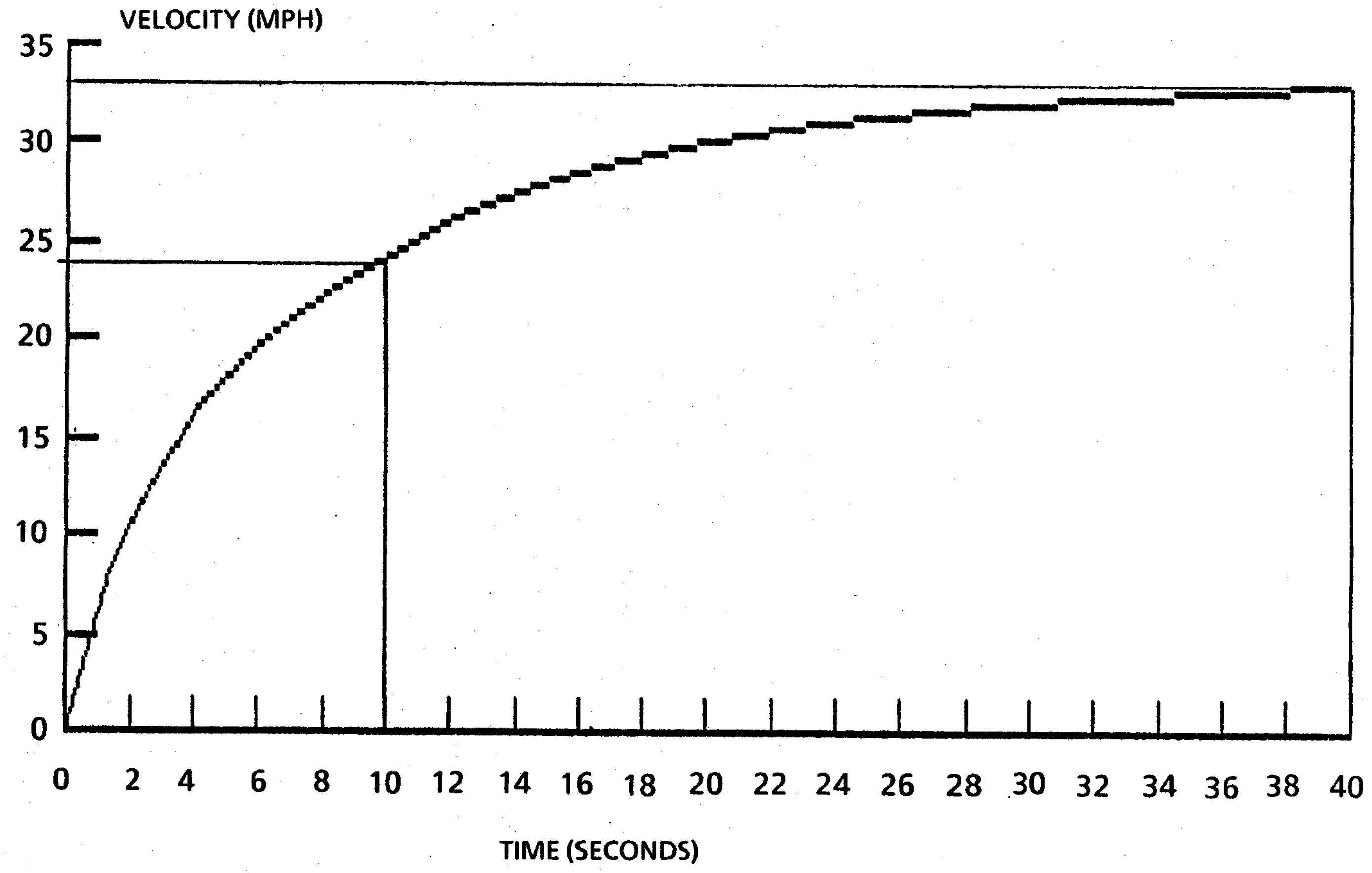
FIGURE 3-4. VEHICLE ACCELERATION VERSUS VELOCITY FOR A 1986 AUDI 5000S IN REVERSE GEAR WITH A 20° THROTTLE ANGLE (without brakes applied)



DISTANCE (FEET)

SOURCE: Based on TSC calculations.

FIGURE 3-5. VEHICLE VELOCITY VERSUS DISTANCE FOR A 1986 AUDI 5000S IN REVERSE GEAR WITH A 20° THROTTLE ANGLE (without brakes applied)



SOURCE: Based on TSC calculations.

FIGURE 3-6. VEHICLE VELOCITY VERSUS TIME FOR A 1986 AUDI 5000S IN REVERSE GEAR WITH A 20° THROTTLE ANGLE (without brakes applied)

3.4 CONTROL UNIT AND SENSORS

Airflow is determined by the electrical current passing through the stabilizer valve, which is set by the ECU, as shown in Figure 3-7. As mentioned above, two significantly different versions of the valve and controller are in use: the rotary and the linear. The former uses a three-wire system with + 12 V DC applied to pin 2. Pins 1 and 3 return to ground through the ECU. The relative proportions of time that current is permitted to flow in each side of the circuit by the controller determine the valve position.

The following test data were recorded by TSC. In the linear valve, Figure 3-8, a spring exerts a closing force. A single solenoid opens the valve by an amount which is proportional to the strength of the current flowing through it. This current normally consists of a pulse train with a frequency of 140 to 150 Hz. The width of the "on" pulses varies from about 1.2 msec at an idle speed of 800 RPM to around 1.5 msec for 1000 RPM. Nominal current for a warm engine is about 430 mA (equivalent DC current). Switching on the air conditioner causes the ECU to increase the current by 60 to 70 mA. The ECU also receives inputs from a temperature sensor and a switch on the throttle. When the engine temperature is below 40° C, an additional 100 mA are provided. When the throttle is open, the working range of currents provided by the ECU is reduced, but it usually remains close to the above-mentioned values.

The most important input to the ECU is engine RPM, taken from the ignition coil primary. These pulses are fed to a frequency-to-voltage converter circuit in the ECU. After passing through a filter stage, a smoothed voltage proportional to engine speed is obtained. This voltage is then compared with a reference voltage, the value of which is dependent upon engine temperature and whether or not the air conditioner is in use. If the actual engine speed proportional voltage is lower than the reference, an output signal is sent to the pulse-width modulator to increase the duty cycle; the converse is true when proportional voltage exceeds the reference voltage. The output from the modulator is then amplified to control the effective current through the idle-stabilizer valve. Figure 3-9 shows the block diagram for the ECU.

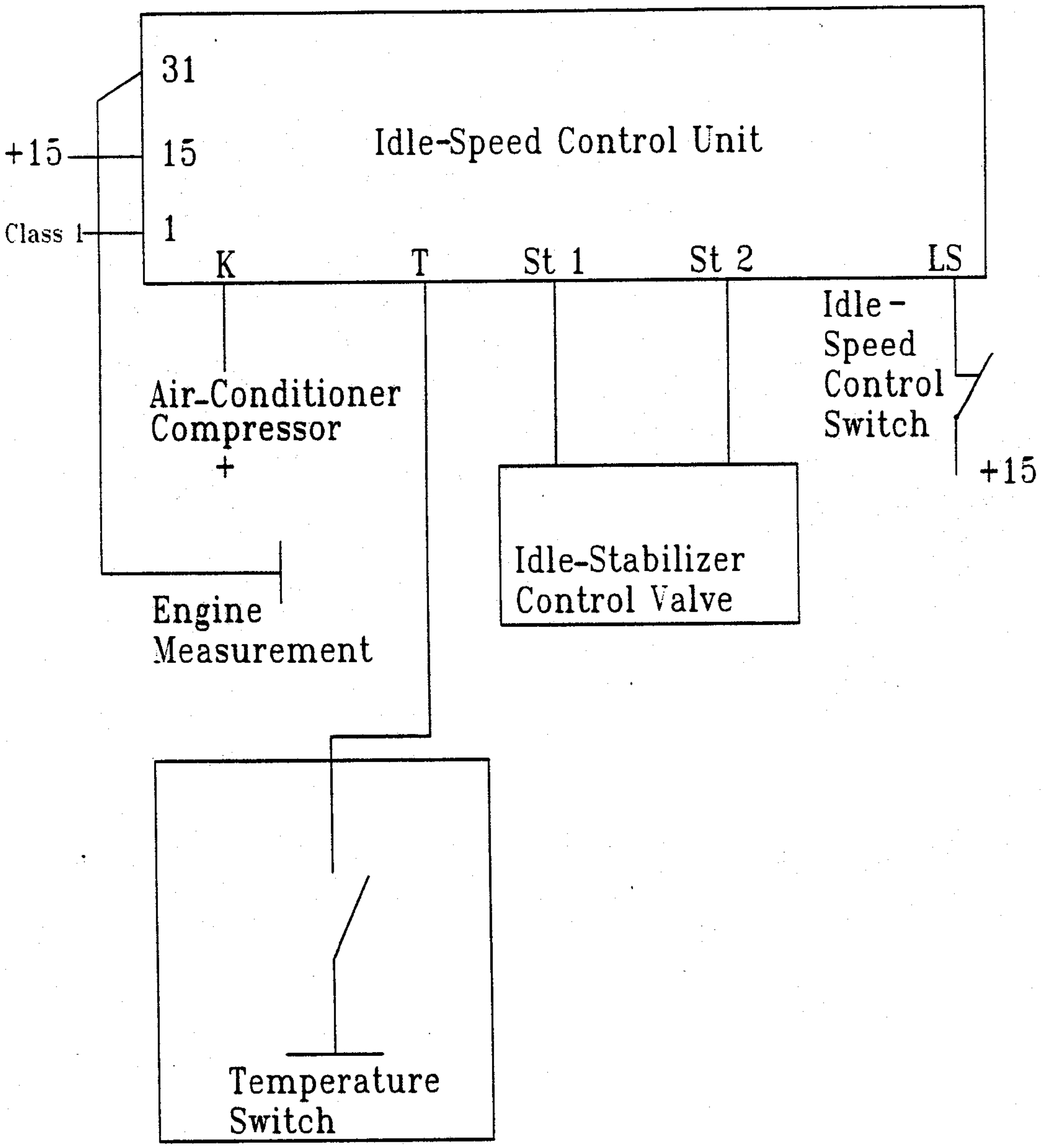
The ECU circuitry consists of a dozen operational amplifiers, a few discrete transistors, about 80 resistors and capacitors, and a few other components. These are mounted upon a pair of circuit boards, each measuring 59 by 54 mm, and joined by a ribbon cable. The two are then folded together so they can be inserted into a molded plastic housing with external dimensions of 61 by 62 by 31 mm. Figure 3-10 shows both boards spread out.

3.4.1 Failure Analysis

In an electronic device as complex as the ECU, there are hundreds of potential failures. Each of the nearly 100 discrete parts can open, short, or drift from its nominal value. Furthermore, each has two or more solder joints which may open, usually intermittently. Each of the integrated circuits has a large number of potential failure modes. Fortunately, the normal failure rates for all these devices are extremely low. Mean times between failures (MTBF) on the order of millions of hours are the norm as long as electronic components are used within their rated environmental limits. However, as a rule of thumb, each 10° C temperature rise reduces MTBF by an order of magnitude.

Of these hundreds of possible failure modes, a great many reduce or completely cut off current flow through the valve. As a result, the car will be difficult to drive because of engine stalling, but this poses no other safety hazard.

Of far greater concern are those failures leading to abnormally large currents. Some of these produce only a moderate increase in valve opening. ODI has supplied data indicating that Canadian



SOURCE: From VWOA through ODI to TSC, translated to English from German by TSC.

FIGURE 3-7. WIRING DIAGRAM FOR THE IDLE-STABILIZATION CONTROL SYSTEM

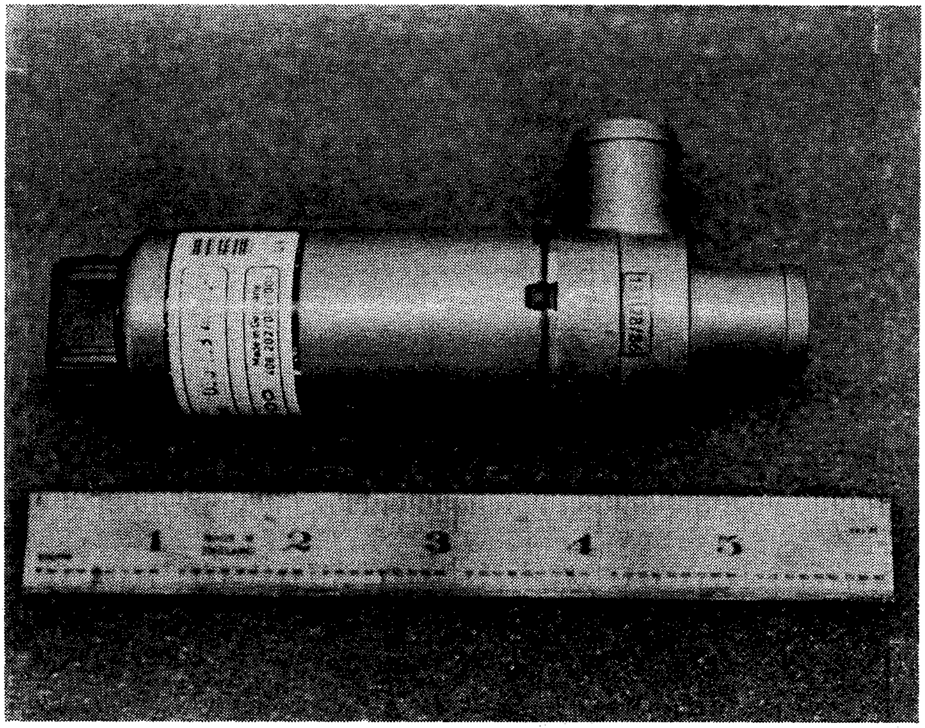
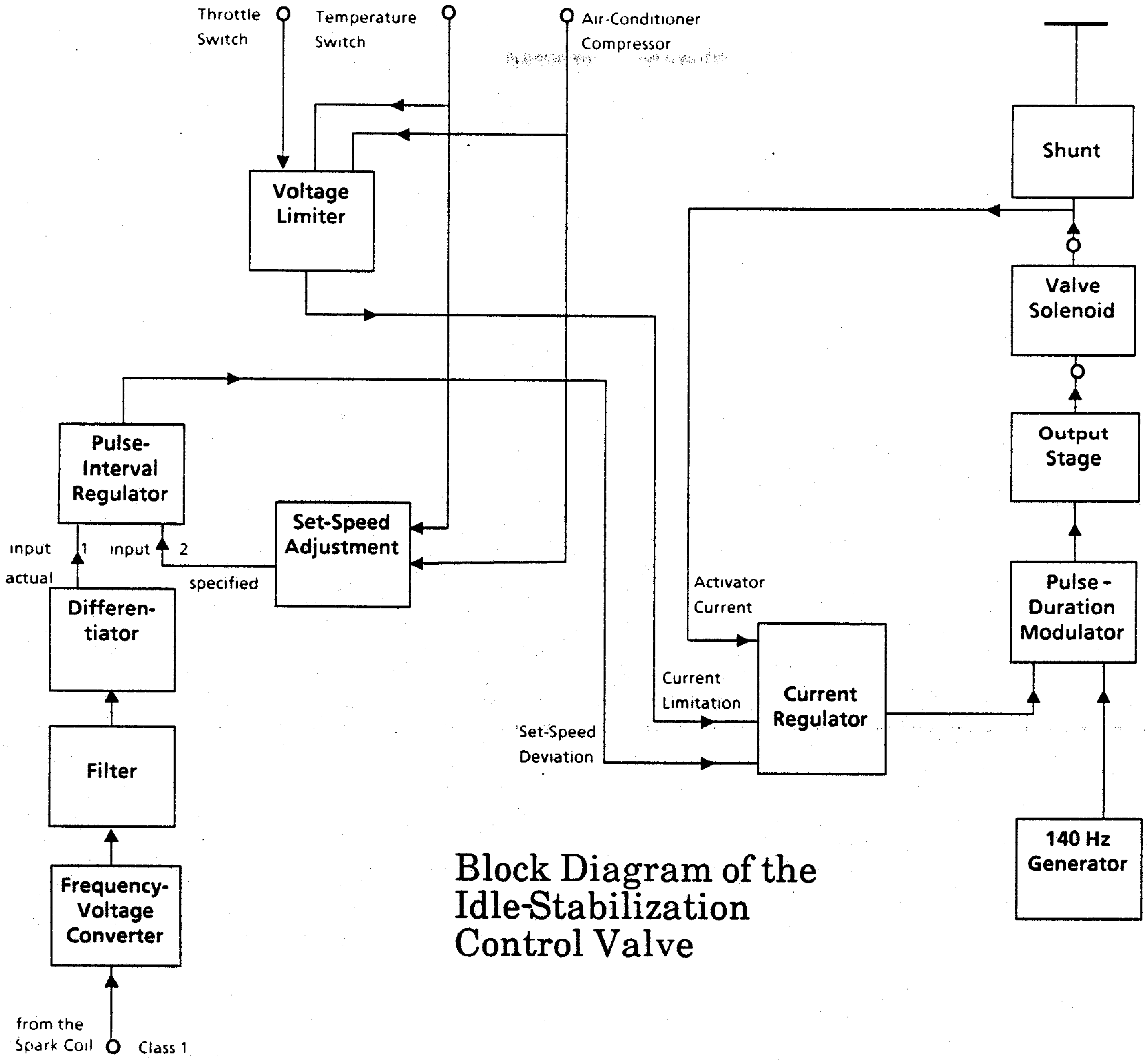


FIGURE 3-8. LINEAR-ACTUATED IDLE-STABILIZATION VALVE



SOURCE: From VWOA through ODI to TSC, translated to English from German by TSC.

FIGURE 3-9. BLOCK DIAGRAM OF THE IDLE-STABILIZATION CONTROL VALVE

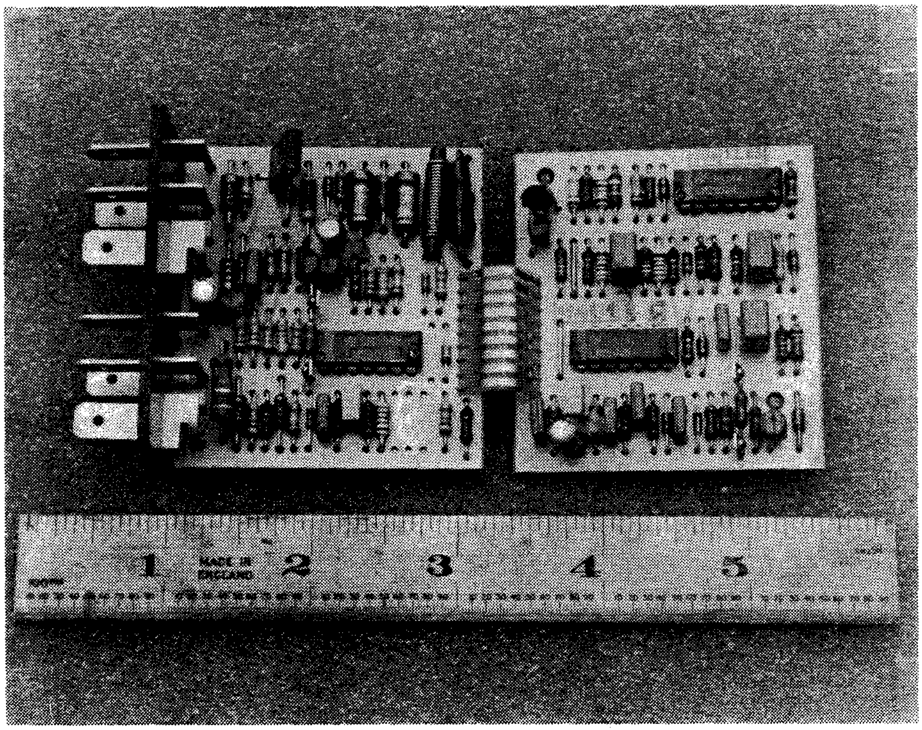


FIGURE 3-10. CIRCUIT BOARDS COMPRISING THE ELECTRONIC CONTROL UNIT (ECU).

investigators found an intermittent solder joint on a capacitor in the circuit which smoothes the output from the frequency converter. This fault led to an idle speed of about 1800 RPM.

Most serious are the faults which drive maximum current through the valve. Full valve opening is achieved with about 1 amp, which can produce an initial acceleration of up to 0.3 g. Level road speeds of about 40 mph in drive or 33 mph in reverse can result.

Among the most likely causes of high current faults are shorts in the output transistor, T145, or the driver transistor, T143, shown in Figure 3-11. Shorts in either will lead to currents limited only by the resistance of the valve and shunt, or about 2.3 amps. Such currents were, in fact, measured repeatedly during acceleration incidents with a test vehicle. These test results are contained in Appendix D.

Excessive temperatures in the ECU are the most likely cause of intermittent shorts in the output and driver transistors. TSC laboratory measurements of the case temperature of a driver transistor have shown it to be as much as 45° C above ambient. NHTSA field measurements on a hot, sunny day indicate initial ambient temperatures inside the ECU box can easily exceed 50° C. Thus, these components may be commonly exposed to temperatures above 70° C, which is considered the desirable upper limit for most commercial-grade devices.

In a laboratory experiment, one ECU which had tested normally for 2 weeks of continuous operation was placed in an environmental chamber. It continued normally until the temperature was raised to 55° C. Thereafter, even when operating at room temperature, it intermittently exhibited either normal behavior or one of four distinct abnormal modes. One of these abnormal states resulted in no output while another yielded about 25 percent of the normal current. The other two provided normal current but at greatly elevated pulse rates, 3.5 and 7 kHz respectively. Tapping or flexing the output transistor could cause the control to jump between fault states or back to normal. (Operation at normal current, but at a very high pulse rate of 28 kHz, was often exhibited by the ECU from the test car just prior to its intermittent jumps into the shorted, maximum-current fault mode. This observed high-frequency pulse was an indicator to a failure of high current.)

In addition to excessive temperatures arising from the ECU design combined with summer ambients, it is likely that the output transistors of some ECUs may have been damaged by faulty diagnostic procedures used by some mechanics. Testing the control requires measuring its output current. However, the ammeter must be inserted between the ECU and the valve, since there is a shunt resistor in the return to ground which provides essential feedback to the output stage. If this feedback is eliminated by connecting an ammeter from the low side of the valve to ground, the output stage will be driven full on and will overheat. Audi has acknowledged this problem and has added a current limiter to the most recent version of the ECU to make it invulnerable to such mechanic errors.

Another faulty ECU was tested for 2 months by TSC. During the first 2 weeks of testing there were 5 incidents in which the output current rose to about 1 amp. These faults were definitely not caused by the output stage, but the exact failing component was not determined. Following a thorough cleaning of the circuit board, no further incidents occurred in 6 weeks of testing. Hence, a possible explanation for the abnormalities in this unit is that a fleck of solder adhered to the board when it was assembled and caused intermittent shorts until it was removed during cleaning.

3.5 IDLE-STABILIZER VALVE

The rotary-type valve of the idle-stabilizer system was analyzed to determine if a malfunction in the valve could keep it open with a normally functioning control unit or if an improperly operating control unit could force the valve open. Three types of possible failures were examined: a mechanical sticking of the valve, an intermittent connection between the brushes and current collectors, and a broken return spring. Appendix A gives a detailed description of these possible failure modes.

Figure 3-12 (a) shows the orientation of the valve's electrical components and sign naming conventions. A diagram of the electrical circuit within the armature for normal operation is shown in Figure 3-12 (b). Pins 1, 2, and 3 are connected to brushes that run against a segmented current collector mounted to the armature. The rotary valve uses an armature that is not mechanically restricted to 120° of travel. Since the brushes are mounted 120° apart, the brushes can contact adjacent current-collector segments. If contact were to occur, the current in the windings would change direction and, in turn, reverse the torques applied by the windings. When the brushes contact adjacent current-collector segments, overrun conditions occur (see Appendix A). The two possible overrun positions are the overrun open (valve open) and the overrun closed (valve closed) positions. In the overrun condition, the torque required to hold the valve open is reduced. The torque needed to hold the valve open when the control unit is sending a closing duty cycle while the armature is in the overrun open position is about 4.5 oz-in. To develop this torque a mechanical sticking must occur. Mechanical sticking could be caused by a bearing failure or a brush–current-collector failure. In the event of a bearing failure, the mechanical sticking is developed by the binding of the armature bearings onto the support shaft. In the event of the brush–current-collector failure, arcing of the brush and the collector causes the brush to weld itself to the collector. Under both of these mechanical failures, the valve would not return to proper operation and physical evidence of a defective valve would remain after an SAI. If the valve was in the overrun open position and all the components functioned properly, the valve would always return to the commanded equilibrium position.

A second type of failure would occur if the current collector deteriorated at some location that would cause it to become insulated from the brushes (i.e., create a dead spot). The dead spot would interrupt the flow of current being sent by the control unit. The resulting interruption in current would reduce the torque produced by the winding and allow the return spring to return the armature to the neutral position. As the armature starts to return to the neutral position, the dead spot is bypassed and the current starts to flow again. This intermittent opening of the circuit would cause the valve to develop large oscillations that would produce engine surging and perhaps a premature fatigue failure of the spring. It has been reported by ODI that some of the idle-stabilizer valves replaced by the recall campaign (July 1986) caused engine surging up to 3800 RPM in neutral or park.

If the spring failed due to large oscillations, the valve would still operate. Without the resisting torque of the spring, the valve would respond faster to the signals present and have a greater tendency to enter the overrun condition. Figure 3-13 shows the condition where the valve is commanded to fully close and the spring is broken. If the valve started above the 94° position and received the command to close, the closing torque of -8.3 oz-in would change to an opening torque of 6.0 oz-in. Even with a closing signal, this change in torque would cause the valve to continue to open. If the spring were broken or defective and the valve was in the overrun open position, a normal closing signal would continue to open the valve. If the power were shut off after an overrun condition and the valve drifted to less than 94°, the valve would return to the broken spring operation. During broken spring operation the engine might surge to a greater extent than normal, without necessarily seeming out of the ordinary. Testing the valve according to the Audi Factory Repair Manual could show normal valve operation. This test checks the engine RPM at the 28 percent duty cycle as

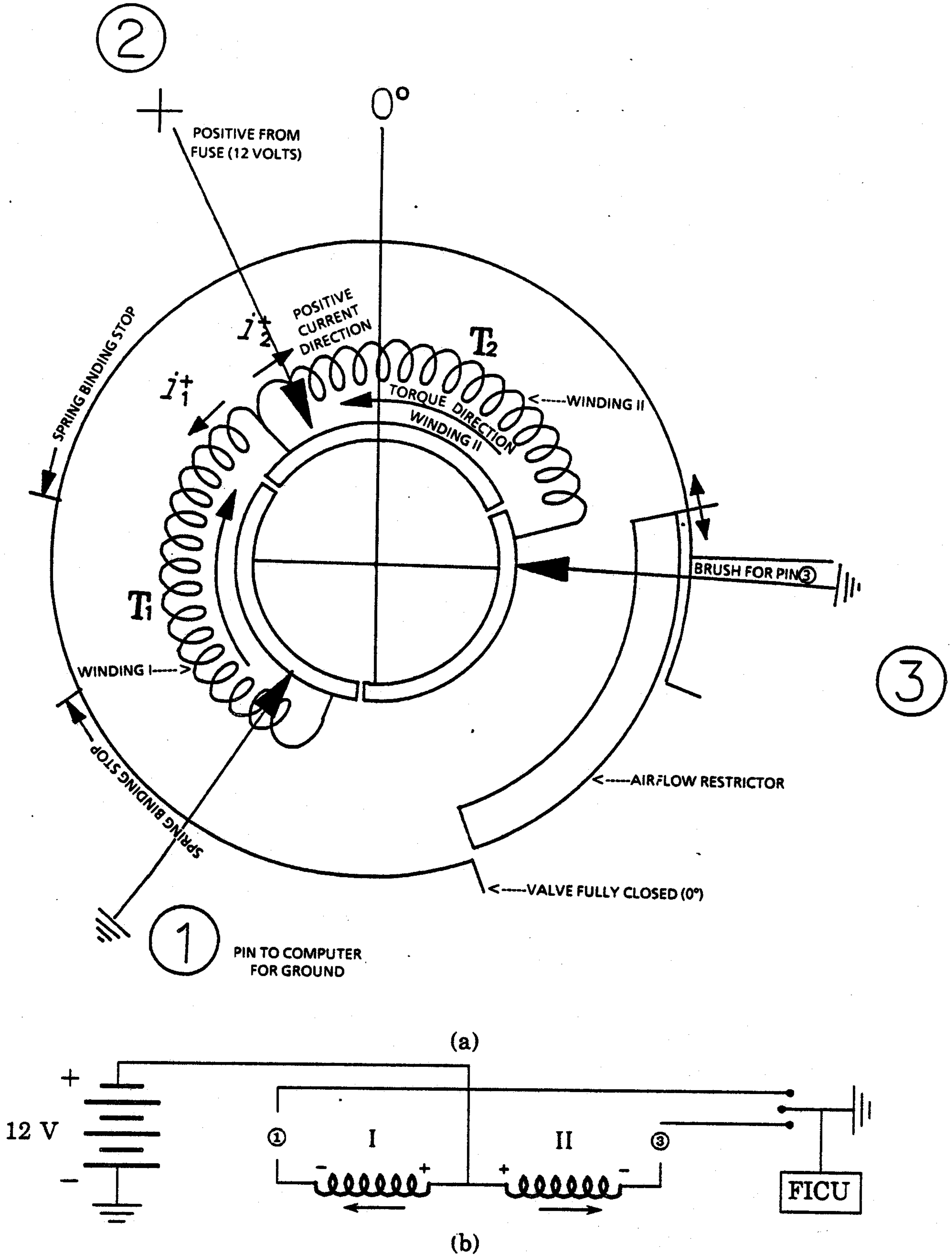


FIGURE 3-12. ORIENTATION OF VALVE COMPONENTS AND SIGN CONVENTIONS UNDER NORMAL OPERATION

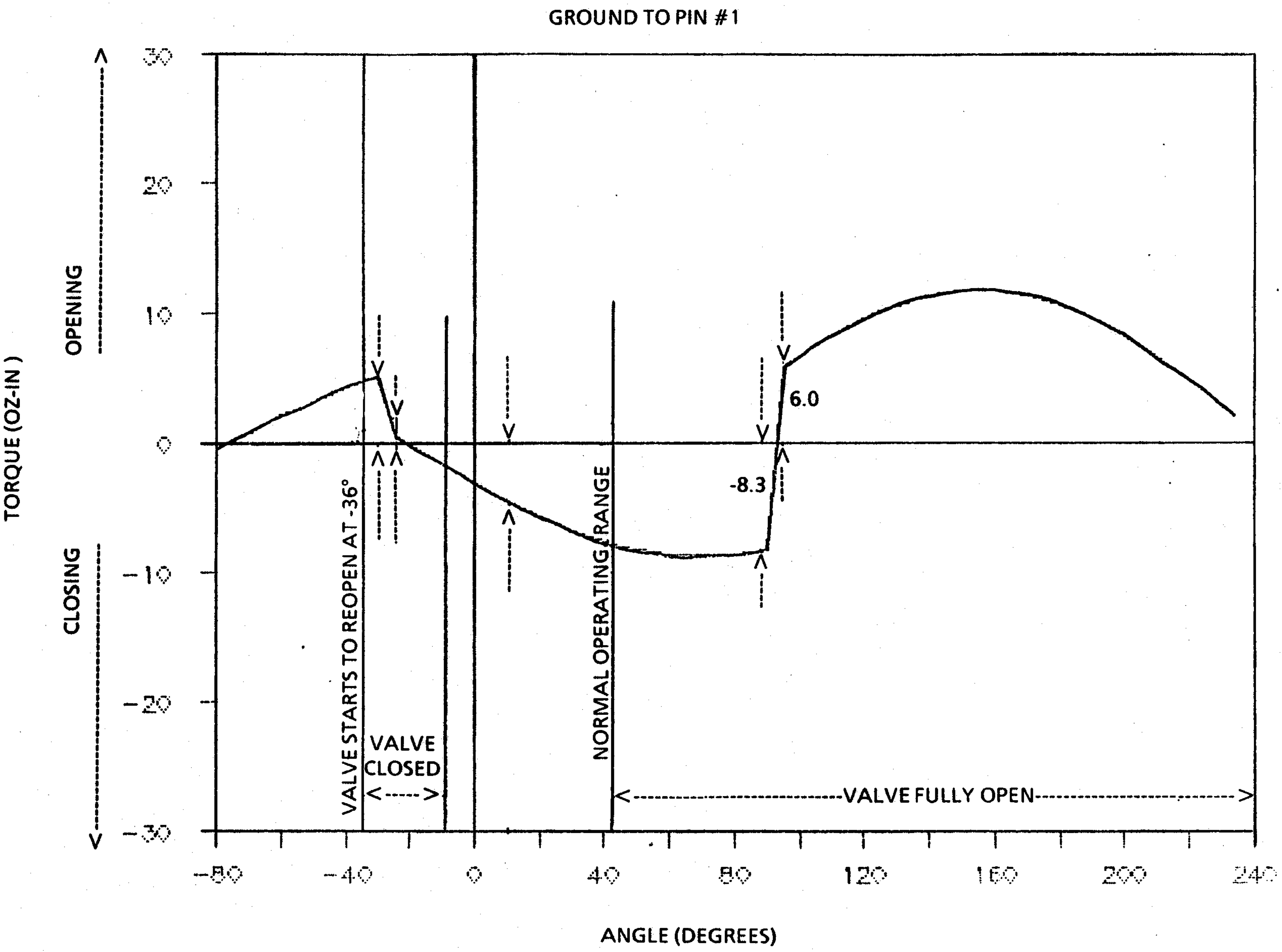


FIGURE 3-13. TORQUE ON ARMATURE VERSUS VALVE OPENING ANGLE FOR THE COMMAND TO FULLY CLOSE WITH SPRING BROKEN

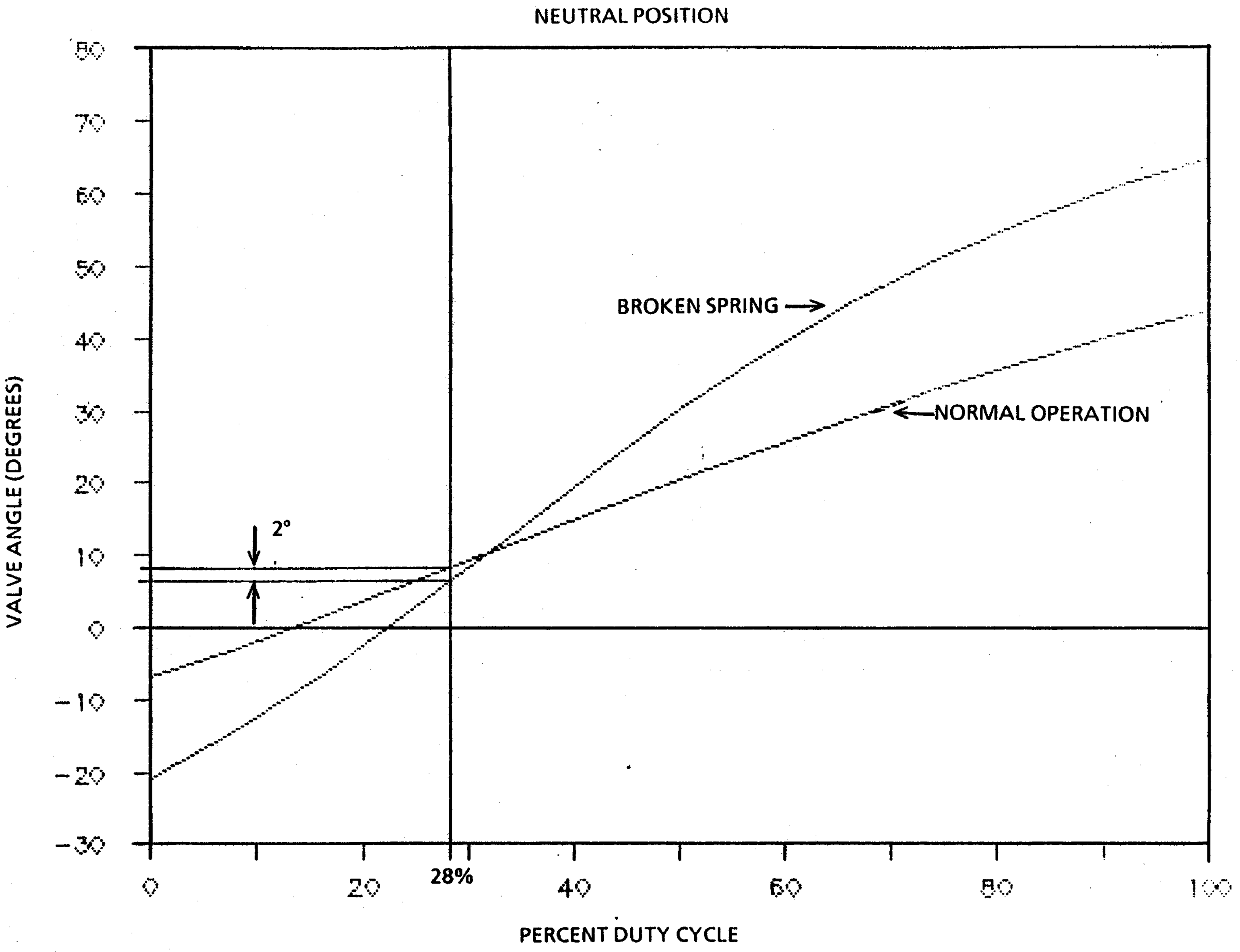


FIGURE 3-14. OPENING ANGLE OF VALVE AS A FUNCTION OF PERCENT DUTY CYCLE ON WINDING 1 DURING NORMAL AND BROKEN SPRING OPERATION

described in Appendix A. As shown in Figure 3-14, at the testing location of 28 percent, the difference in the valve angle with and without the spring is about 2.0°. The mechanical sticking or the intermittent connection failures are easily detected by inspection or by the condition of the engine idle. Of the three possible valve failures, only a broken spring failure could cause the valve to remain fully open with the control unit sending a normal closing signal, and then properly operate after the power has been shut off. The standard tests used to determine the valve's condition would not detect a broken spring unless in the overrun condition. If the spring is broken, the chances of the valve overrunning are high, causing multiple incidents to occur with a single valve. This is not typical of SAIs.

4. CRUISE CONTROL SYSTEM

4.1 INTRODUCTION

Because the cruise control system is capable of opening the throttle plate fully, it was closely studied and preliminary, limited bench testing of four units was performed. Figure 4-1 summarizes failure possibilities with the cruise control system. The cruise control system maintains a constant vehicle speed that has been set by the driver through a computer control unit that monitors the difference between the driver's preset speed and the vehicle's actual speed. The control unit then adjusts the vehicle's speed by adjusting the engine's power. Engine power is changed by adjusting the throttle position. A pneumatic system was used to open the throttle plate on models from 1984 to the present. Previous to 1984, some of the vehicles used an electrical system to open the throttle plate. The control unit for the 1978 to 1983 models was an analog design. After 1983, the control unit was converted to a digital design. The pneumatic system is covered in more detail since it is still being used in the new Audi 5000.

4.2 PNEUMATIC SYSTEM

The components of the pneumatic system are shown in Figure 4-2. They include a vacuum pump, a vacuum motor, a mechanical air bleed, an electrical air bleed, the linkage, and the throttle return spring. The pneumatic system of the cruise control opens and closes the throttle plate. When a vacuum is applied to the vacuum motor, the throttle plate opens. A decrease in vacuum allows the return spring to close the throttle plate. The vacuum level is adjusted by the control unit. When driving conditions demand an increase in vehicle speed, the control unit activates the vacuum pump. If a decrease in vehicle speed is needed, the control unit opens an electrical air bleed that allows atmospheric pressure into the system. As a result, the throttle plate closes. Fine control of vehicle speed can be maintained with this system.

When the brakes are applied, a mechanical air bleed and an electrical switch are activated. The electrical switch sends a signal to the control unit to open the electrical air bleed and turn off the vacuum pump, while the motion of the brake pedal mechanically opens the mechanical air bleed. Immediately after the air bleeds are opened, the vacuum in the vacuum motor is emptied and the throttle plate returns to the fully closed position.

4.3 CONTROL UNIT AND SENSORS

The control unit receives signals from the brake switch, an induction generator, and the driver's operating switch. The control system is shown in Figure 4-3. Mounted behind the speedometer and attached to the speedometer cable, the induction generator develops a signal based on how fast the vehicle is traveling. The driver's operating switch turns the system on and off, sets the vehicle speed, and initiates the resume function. The power to the cruise control system is supplied through the neutral safety switch and the operating switch. The neutral safety switch allows power to the control unit only when the transmission is either in drive or in second gear. If either the neutral safety or operating switch is off, there is no power to the control unit. The electrical air bleed is normally open when there is no power to the control unit. The set switch sends a signal to the control unit to record the current vehicle speed and activate the control system to maintain this speed. The resume switch sends a signal to the control unit to restart the cruise system and maintain the last preset speed. The control unit does not allow these functions to be invoked until the vehicle speed is above 30 mph. To deactivate the cruise system, the brake pedal is depressed or the operator switch is turned off.

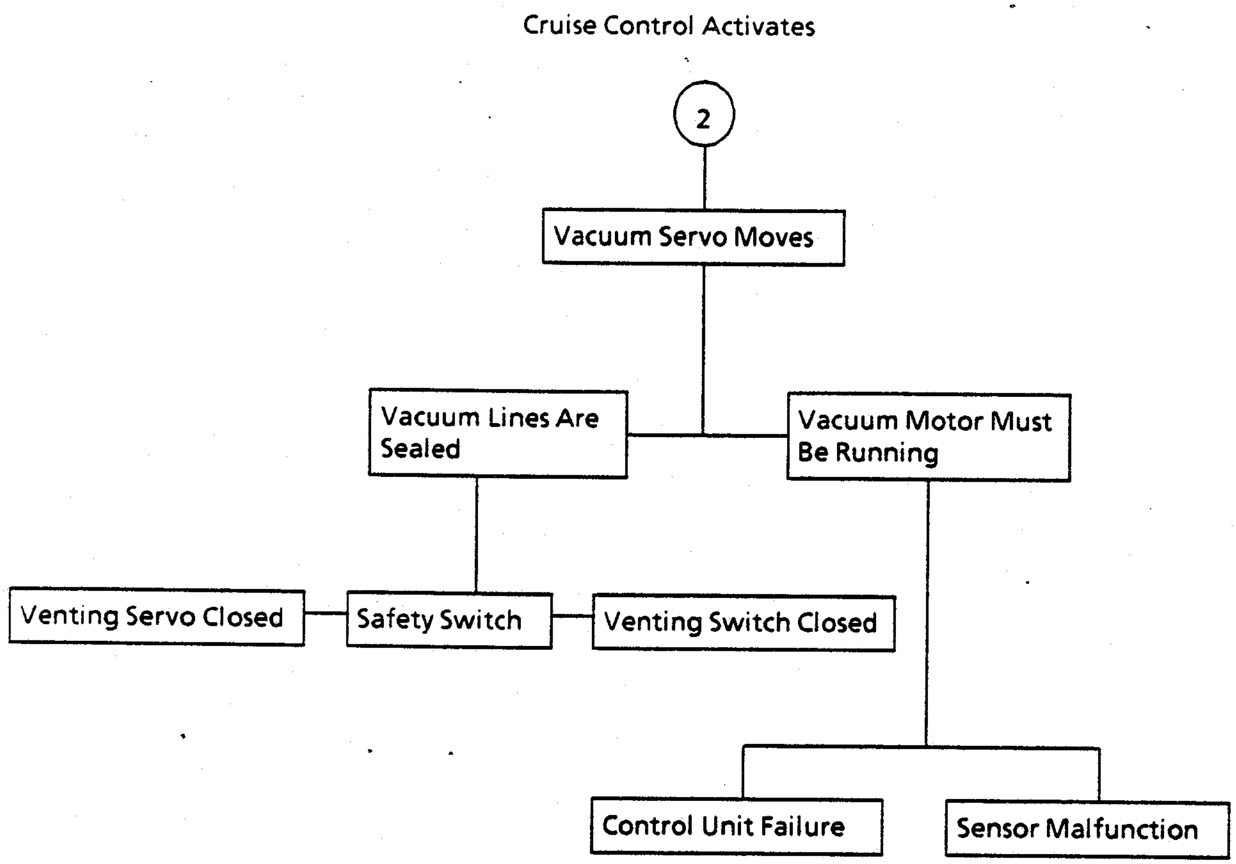


FIGURE 4-1. FAULT TREE ANALYSIS: CRUISE CONTROL

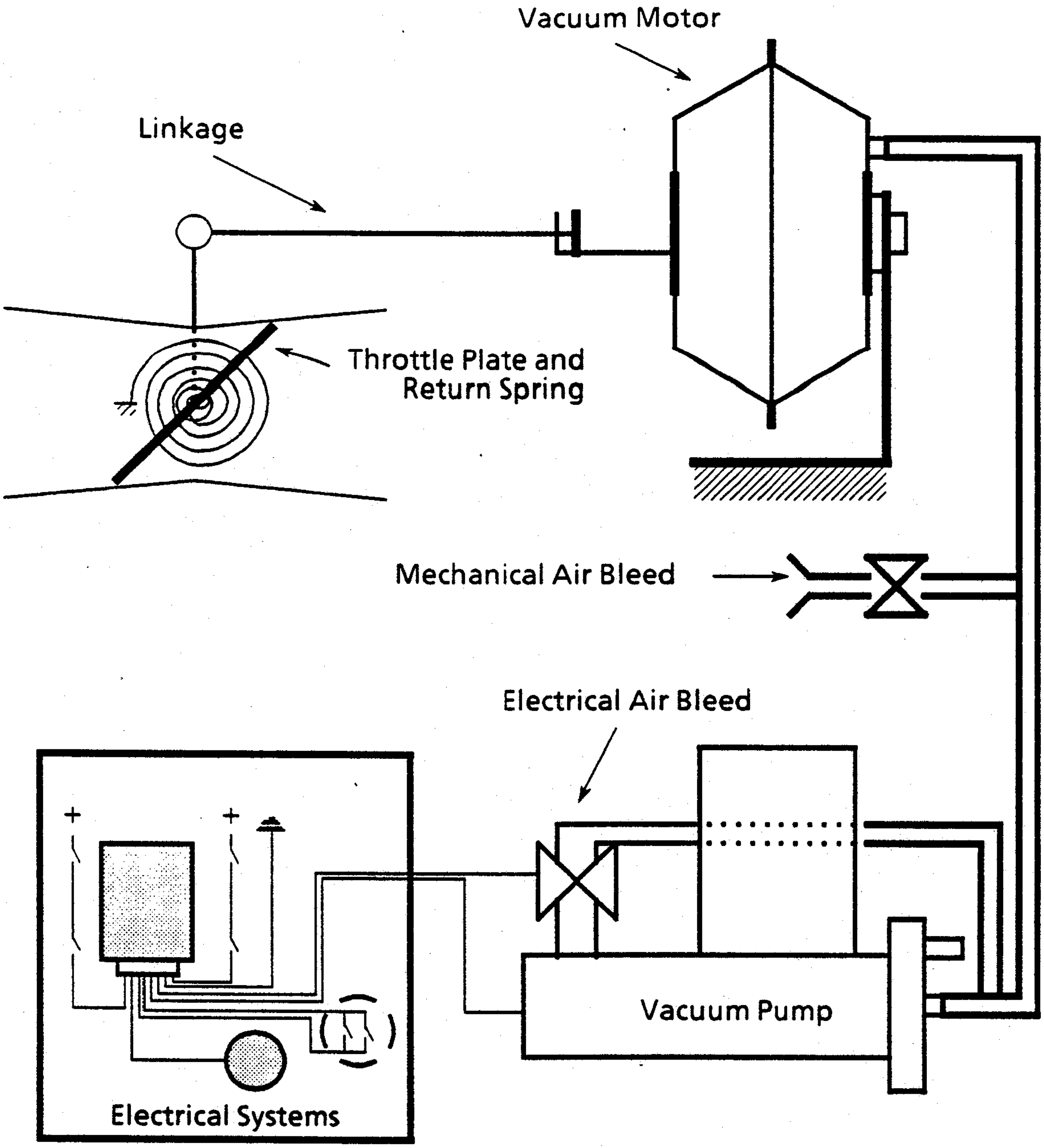


FIGURE 4-2. CRUISE CONTROL PNEUMATICS SYSTEM

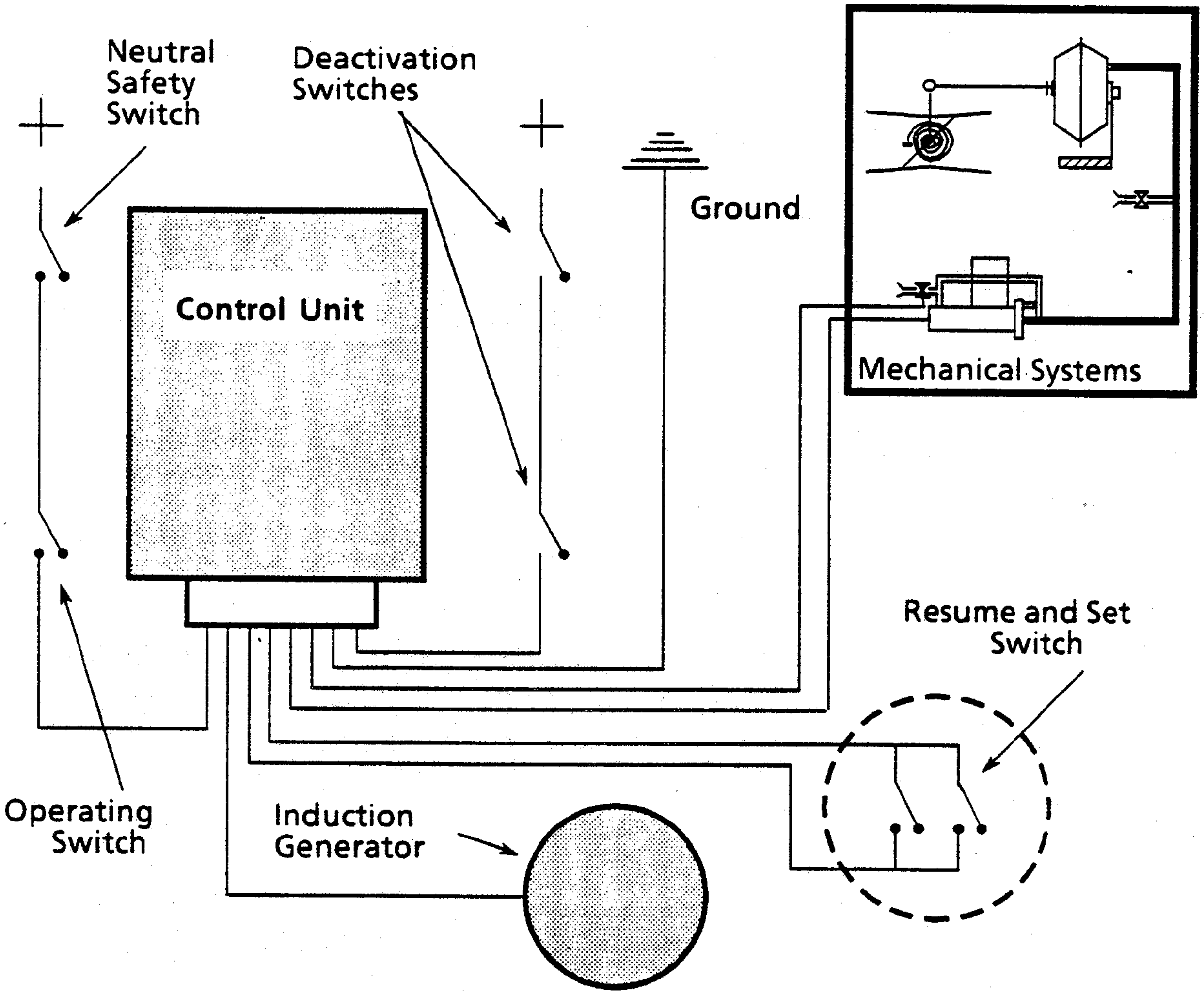


FIGURE 4-3. CRUISE CONTROL COMPUTER CONTROL SYSTEM

4.4 POSSIBLE MODES OF MALFUNCTION

For the cruise control to cause an SAI, the vacuum pump must be operating and both the electrical and mechanical air bleeds must be closed. The vacuum pump and the electrical air bleed are operated by the control unit. A total malfunction of the control unit could open the throttle plate and cause an SAI; however, for this to occur, certain conditions must be met. The control unit is supplied power through the neutral safety switch and the operator switch. Therefore, the vehicle must be either in drive or in second gear, the operator switch must be on, and the brake pedal must not be depressed. If any of these conditions are not met, no SAI could occur. After the SAI has occurred, drivers typically report that the cruise control system operated normally. In addition, SAI reports show that the accidents happen 50 percent of the time in reverse. There is no power to the cruise control in reverse gear even with the operating switch on, unless the neutral safety switch is somehow defective. Such a defect, however, would prevent the vehicle from starting at all.

4.5 CRUISE CONTROL BENCH TEST

Given the case that the vehicle was in drive and the brake pedal was not depressed, it is theoretically possible that certain malfunctions in the cruise control could lead to throttle opening. In the older, analog controller used prior to model year 1984, a single open solder-joint in the final operational amplifier circuit could conceivably cause throttle opening. Other failure modes for this controller and all failure modes for the microprocessor-based controller used afer 1983 would require two or more independent component failures to produce throttle opening. For such failures to cause a throttle-opening incident and yet be difficult to diagnose after the fact, they would have to be of an intermittent nature.

In order to test for the possibility of such intermittent failures, TSC constructed an apparatus in which Audi cruise controls could be operated for extended periods of time with continuous monitoring for fault conditions in the output circuits. This test jog consisted of an Audi vacuum pump, vent and servo together with a power supply, appropriate switches for the "set," "resume" and "brake" inputs, and a pulse generator to simulate the input from the vehicle speed sensor. This jig was placed inside a manually controlled oven so that it could be operated at a temperature of 150 F. because elevated temperatures frequently precipitate electronic failures.

The status of the outputs to the vacuum pump and vent valves was monitored continuously by a digital memory oscilloscope accessory attached to a personal computer. If either of the outputs switched on, however briefly, a record of the anomaly was made.

Each of four Audi controllers (three micro-processor, one analog) was operated for two weeks in the oven at 150 F. From time to time additional thermal stress was applied by manually spraying the circuit boards with freezing mist. During the two months of testing, several anomalies with durations of less than a tenth of a second were recorded. These were probably caused by power surges in the building electrical system (EMI). In no case could they have resulted in measurable throttle opening. No faults of any relevance to SAI were observed.

5. TRANSMISSION

5.1 INTRODUCTION

Because of the direct link between the throttle valve of the engine and the kickdown valve of the transmission, there is a possibility of the transmission, through the linkage, opening the throttle. The transmission can only affect operation as described in this section in 1978 through 1983 Audis; 1984 and later models have reconfigured transmissions for which it is impossible to open the throttle plate by the throttle valve. However, in these later models the transmission gearshift linkage could possibly bind, which would also cause the throttle plate to open.

The following is a discussion of the linkage between the engine and the transmission, and the operation of the automatic transmission. Figure 5-1 shows the linkage fault tree analysis.

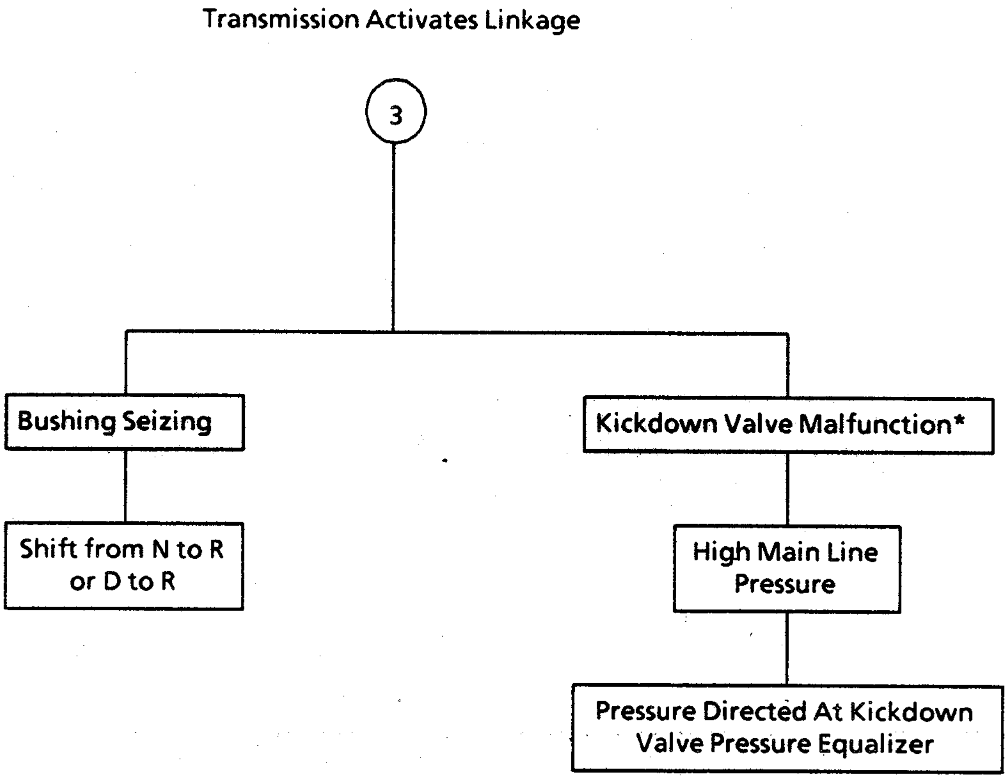
5.2 ENGINE/TRANSMISSION LINKAGE DESCRIPTION

Figure 5-2 shows a schematic of the throttle linkage and the transmission gearshift linkage. The throttle linkage consists of the accelerator pedal and lever, one cable, and five links. The transmission shift linkage consists of the selector lever, a cable, and the shift lever on the transmission. The solid arrows in Figure 5-2 indicate the direction of motion of the links of the throttle linkage when the accelerator pedal is depressed and the dashed arrows indicate the direction of motion when the gear selector is moved from the 'park' position into the 'reverse' or 'drive' position.

When the accelerator pedal is depressed the throttle cable is pulled, which, through five links, opens the throttle plate. The accelerator linkage operating lever, to which the cable is connected, pivots within the shaft of the gearshift linkage selector lever on the transmission. Figure 5-3 shows an exploded view of the selector lever and shaft and the operating lever and how they are mounted on the transmission. The selector lever is mounted on a hollow shaft that goes through the transmission case. The shaft is held in place by a bushing bearing in the transmission case and the manual valve lever is mounted on the shaft inside the transmission. Both levers are fixed to the shaft and when the outside lever – the selector lever – is rotated, the inside lever – the manual valve lever – also rotates. The manual valve lever then changes the position of the manual valve, which shifts from one gear to another. The operating lever is mounted on a solid shaft that is held inside the hollow selector lever shaft by a bushing bearing. Inside the transmission, the operating lever for the kickdown valve is mounted on the operating lever shaft. Again, both levers are fixed to the shaft and rotate together. The operating lever pushes in the kickdown valve; when the operating lever is rotated, the kickdown valve is depressed and the throttle plate opens simultaneously. (The extent to which the kickdown valve is depressed is an operating input for the transmission, and is discussed below.)

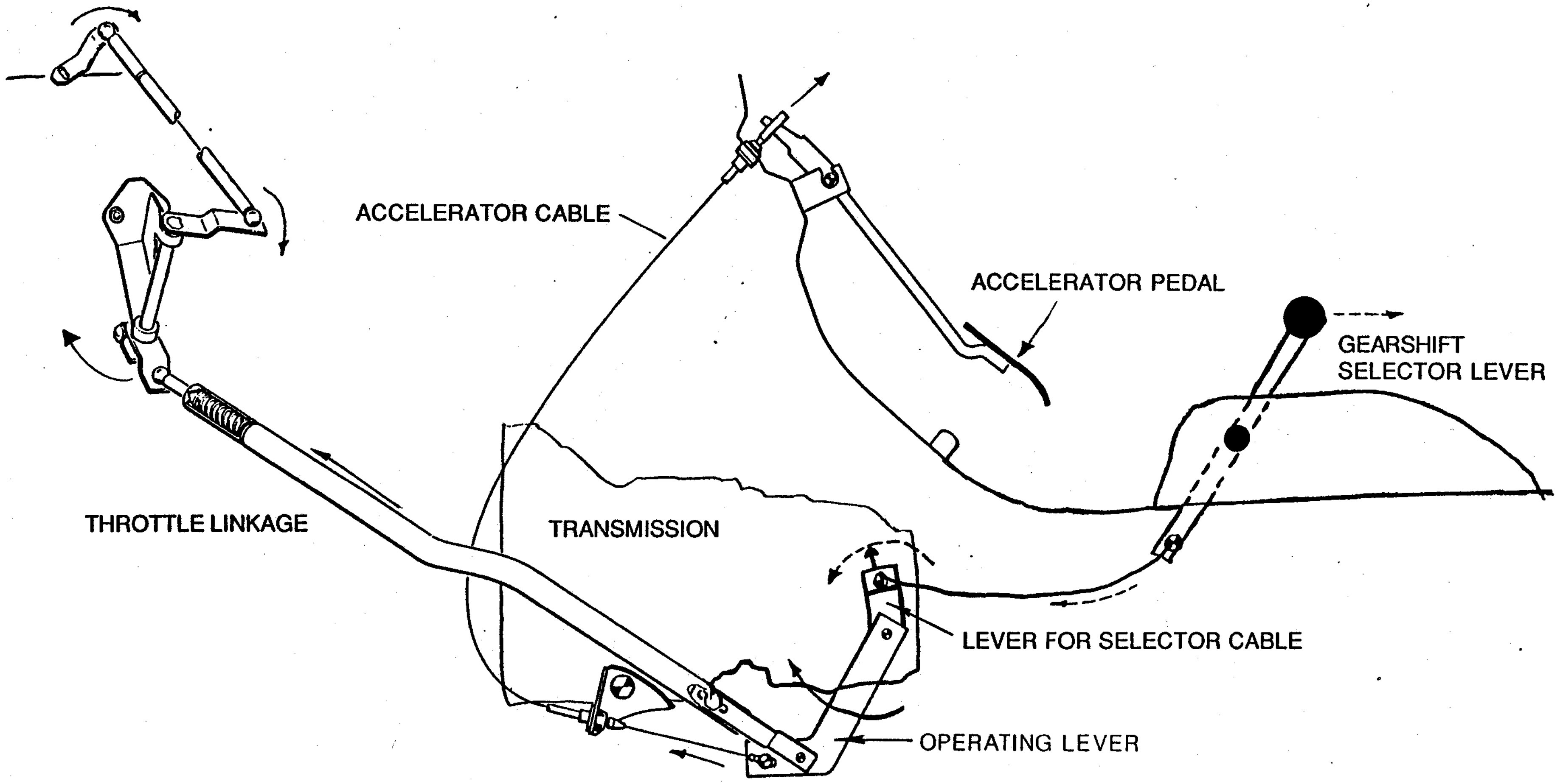
It is possible that the operating lever shaft could bind in the bearing inside the selector lever shaft, causing the two shafts to move together. In this way the gearshift linkage could move the throttle linkage. If this were to occur and the transmission was shifted from park into any other gear, the shift lever on the transmission would act to close the throttle valve. If the transmission was shifted from drive into neutral, reverse, or park, the shift lever on the transmission would act to open the throttle plate.

Two designs have been used for the operating lever for the kickdown valve. In 1983 and earlier transmissions the lever was held captive by the kickdown valve, as shown in Figure 5-4, while in 1984 and later transmissions the lever pushes on the end of the kickdown valve, also shown in Figure 5-4, and the two are not secured together.



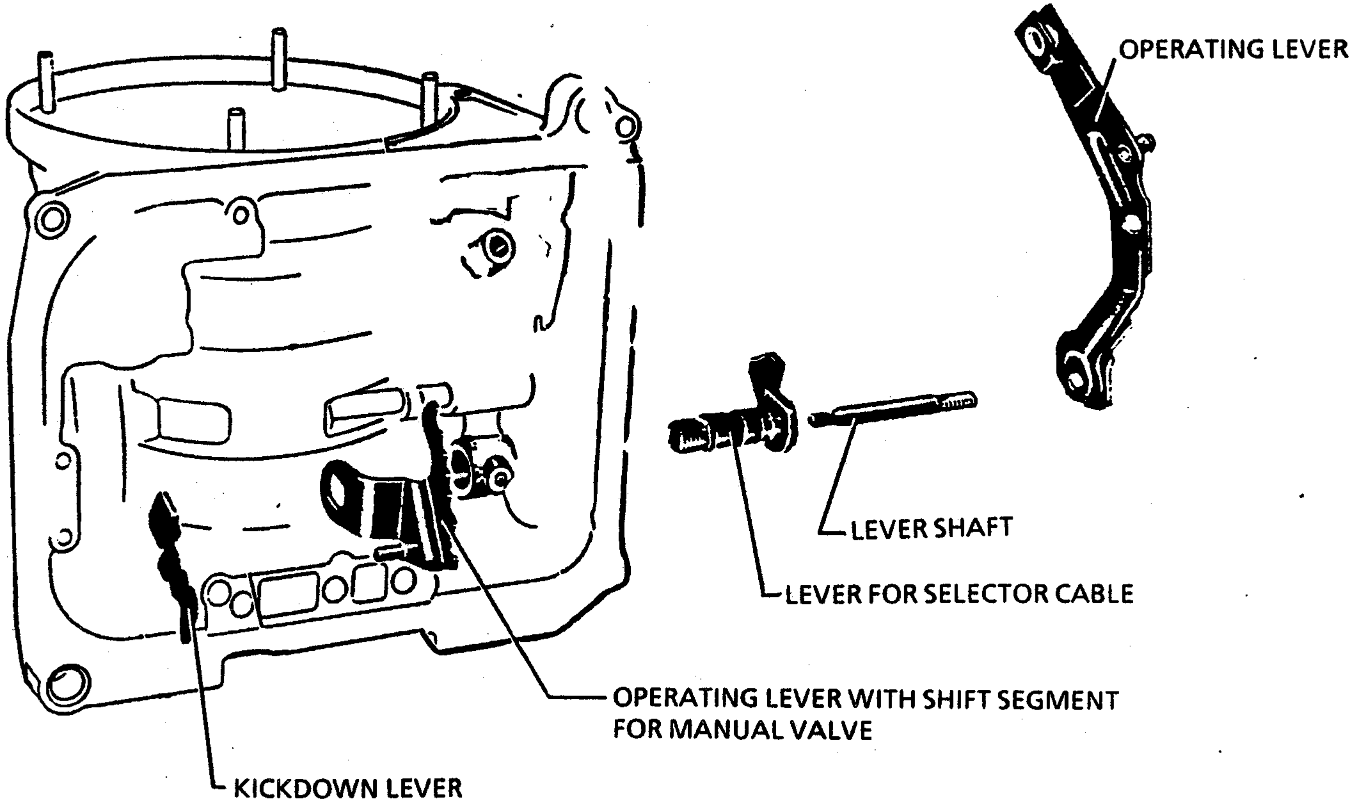
*Does not apply to transmissions from 1984 to 1987

FIGURE 5-1. FAULT TREE ANALYSIS: TRANSMISSION



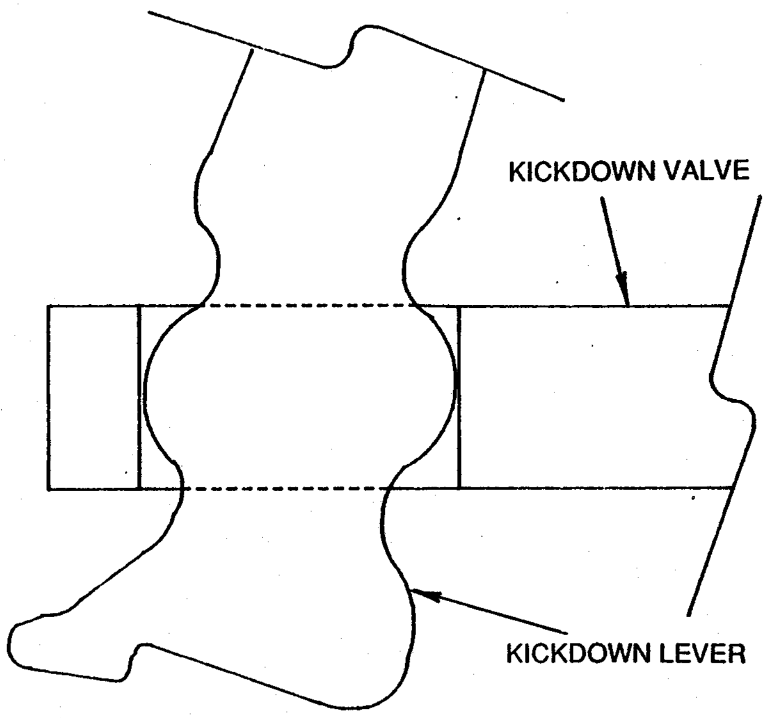
SOURCE: Derived from Official Factory Repair Manual 1983, 37.3.

FIGURE 5-2. SCHEMATIC OF THROTTLE LINKAGE AND TRANSMISSION GEARSHIFT LINKAGE

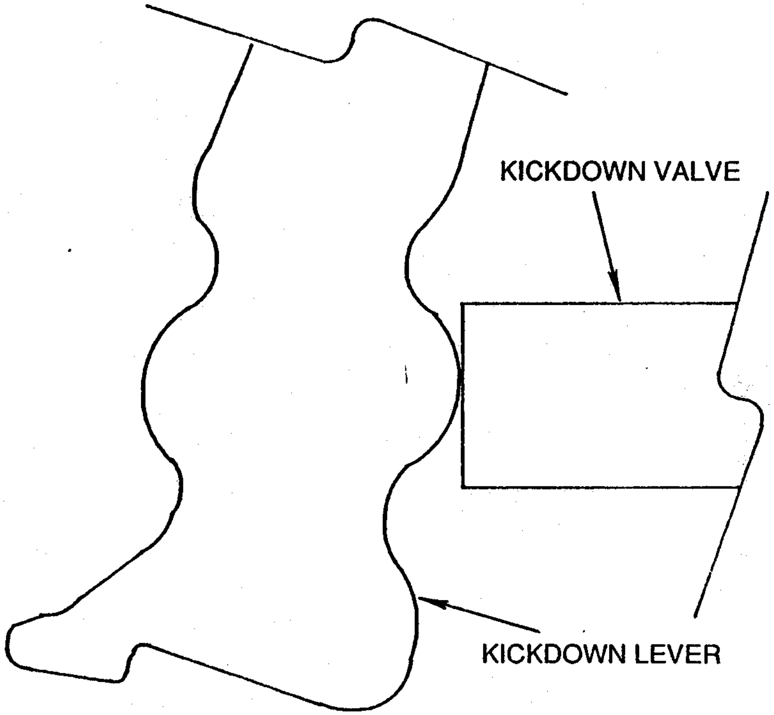


SOURCE: Derived from Official Factory Repair Manual 1983, 38.33.

FIGURE 5-3. SELECTOR LEVER, SELECTOR SHAFT, OPERATING LEVER



PRE-1984



1984 - PRESENT

FIGURE 5-4. OPERATING LEVER FOR KICKDOWN VALVE

For cars equipped with 1983 and earlier transmissions, it is possible for the kickdown valve to pull on the kickdown operating lever, rotating the shaft and the accelerator linkage operating lever on the outside of the transmission which, in turn, through the accelerator linkage, would open the throttle plate. In order for this to happen the kickdown valve would have to malfunction and pull itself in. The operation of the kickdown valve is discussed in the following section.

5.3 AUTOMATIC TRANSMISSION

The automatic transmission in the Audi 5000 automobile is comprised of a torque converter and two sets of planetary gears. The torque converter provides a fluid coupling between the output shaft of the engine and the input shaft of the transmission. The input shaft of the transmission is linked to the output shaft by the two planetary gear sets which are capable of producing three forward gears and one reverse gear. These planetary gear sets can be engaged in various combinations by three clutches and one band which, in turn, are engaged or disengaged to produce the appropriate gear by a 'hydraulic logic' unit called a valve body.

The operation of the transmission is controlled by the valve body. There are three inputs to the valve body: the manual valve position, the governor line pressure, and the kickdown valve position. The position of the manual valve is controlled by the shift lever, the governor line pressure is controlled by the speed of the output shaft of the transmission, and the kickdown valve position is controlled by the throttle angle. The manual valve forces the transmission into the gear selected by moving the shift lever to the appropriate position. The kickdown valve in conjunction with the governor controls the speed at which the transmission shifts and the pressure that is applied to the bands and clutches. When the kickdown valve is fully depressed and the manual valve is in the 'drive' position, the transmission will downshift, either from 3rd gear to 2nd gear or from 2nd gear to 1st. The transmission may also downshift from 3rd to 1st gear.

The valve body assembly is comprised of three subassemblies: the transfer plate, the separation plate, and the valve body. The transfer plate contains pressure channels that allow the various pressures to act on the valves in the valve body. The separation plate determines which pressure channels in the transfer plate are connected to the different pressure channels of the valve body. The valve body subassembly contains the valves that control the operation of the transmission and some additional pressure channels. Figure 5-5 shows the orientation of the valve body, separation plate, and the transfer plate.

5.4 DESCRIPTION OF KICKDOWN VALVE CIRCUIT

Figure 5-6 shows a simplified schematic diagram of the fluid circuit in the valve body that contains the kickdown valve. There are five valves included in the circuit with the kickdown valve: the throttle limit valve (T.V. limit), the throttle valve, the line bias valve, the pressure regulator valve, and the kickdown valve. This diagram is a simplified model that shows the valves that affect and are affected by the kickdown valve when the manual valve is in the 'drive' or 'reverse' position. In these positions, the valves normally function in the following fashion:

The T.V. limit valve decreases the line pressure to the T.V. feed pressure. The T.V. feed pressure is 85 psi if the line pressure is greater than 85 psi, and the T.V. pressure is equal to the line pressure if the line pressure is less than 85 psi. Based on the throttle angle and the T.V. feed pressure, the throttle valve adjusts the T.V. pressure. The T.V. pressure increases with increasing throttle angle, from 5 psi up to the T.V. feed pressure for a maximum T.V. pressure of 85 psi. (The T.V. pressure and the governor line pressure act on the 1-2 and 2-3 shift valves, determining 1-2 shifts and 2-3 shifts, respectively.)

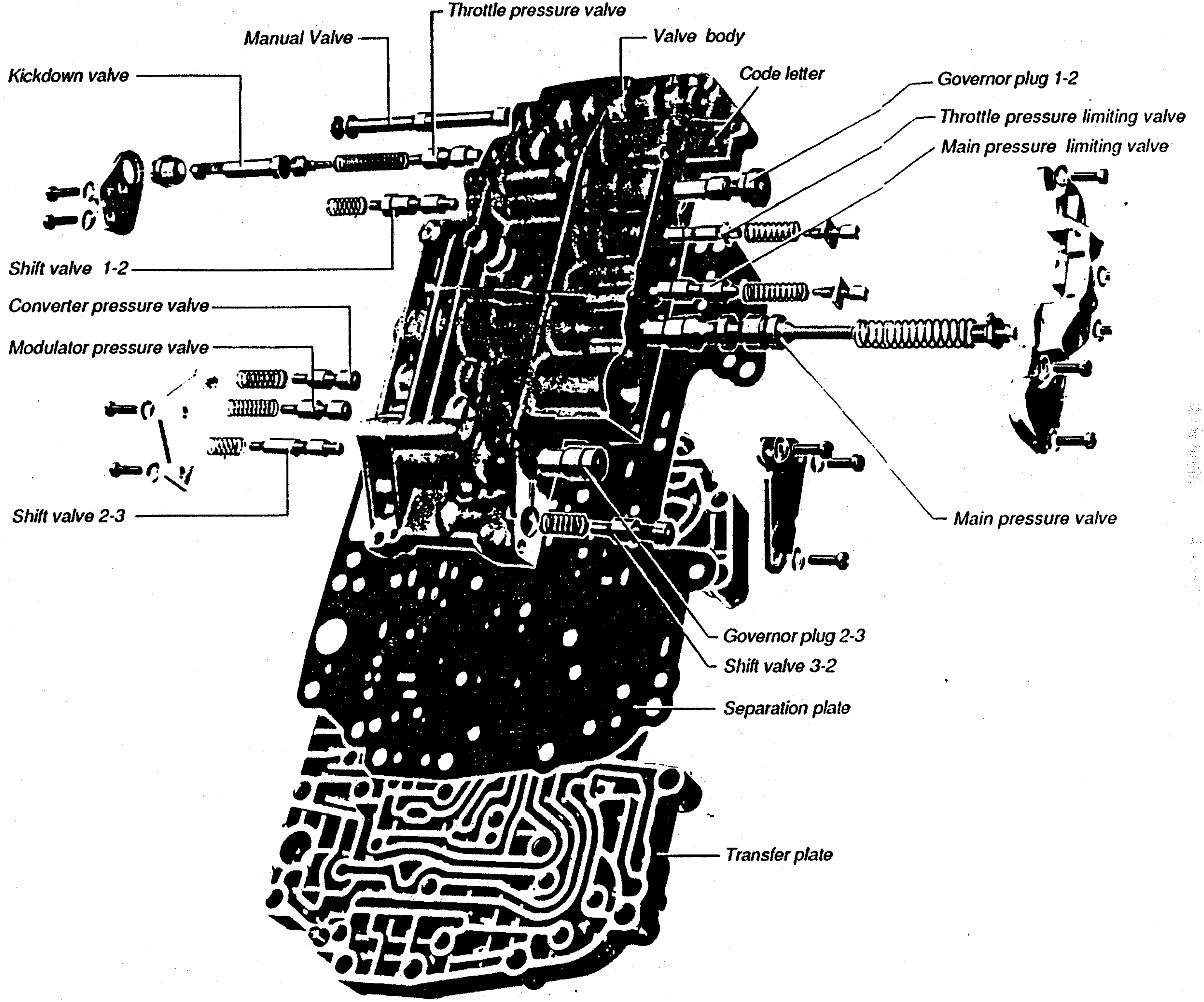


FIGURE 5.5. TYPICAL AUDI 5000 VALVE BODY

SOURCE: Automatic Transmission for Volkswagen and Audi 1974, 40.

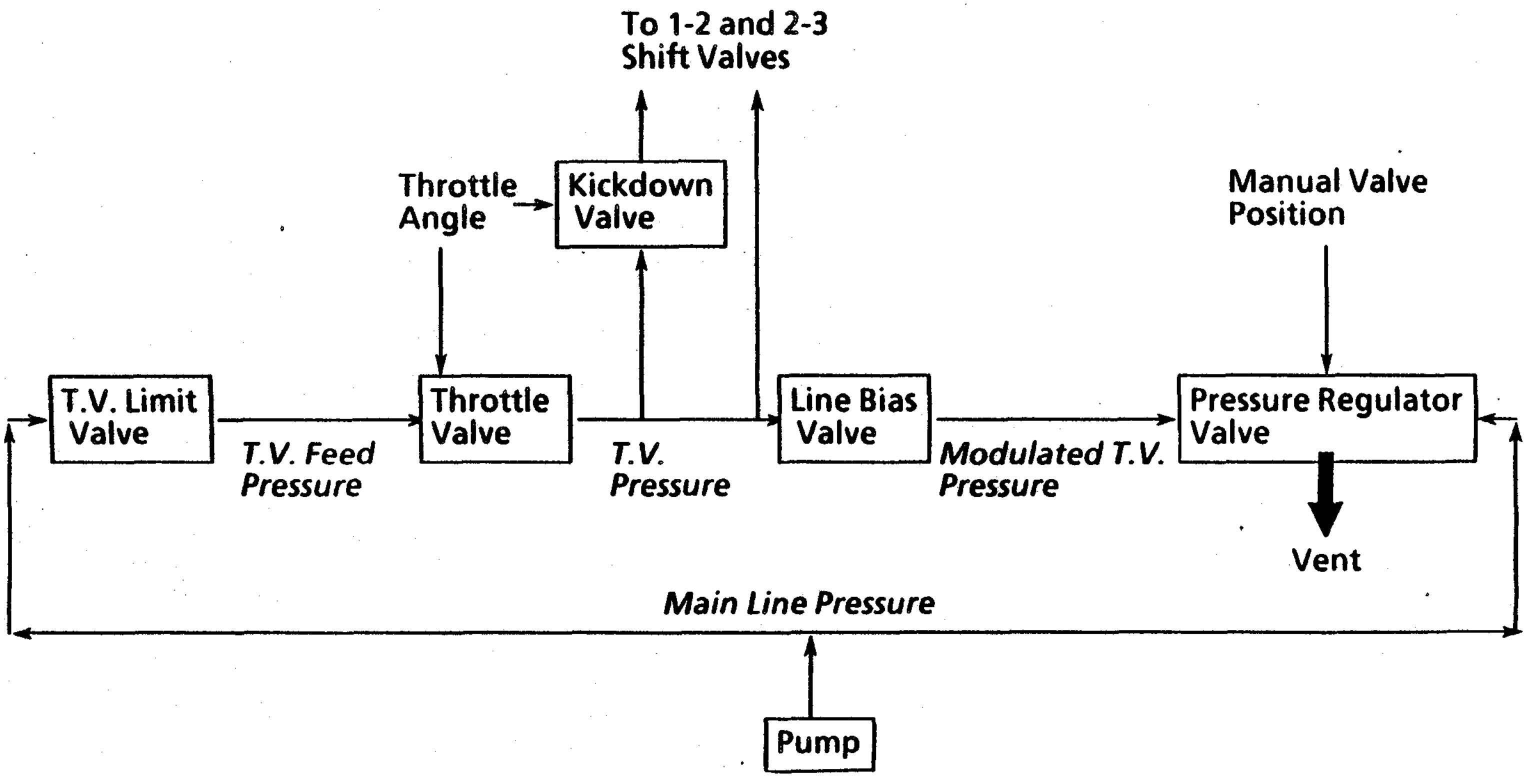


FIGURE 5-6. 1982 MODEL TRANSMISSION KICKDOWN VALVE CIRCUIT

The T.V. pressure acts on the line bias valve to produce the modulated T.V. pressure. The modulated T.V. pressure is limited to a maximum of 30 psi by the line bias valve.

The modulated T.V. pressure and the manual valve position act on the pressure regulator valve, which produces the line pressure. In effect, the pressure regulator valve increases line pressure as the throttle plate angle increases, through the actions of the throttle valve and the line bias valve. The pressure regulator valve also acts to limit the line pressure. This is the only valve in the circuit that behaves differently in reverse than in drive. In reverse, the main line pressure is limited to 300 psi, while in drive it is limited to 130 psi.

The kickdown valve forces the transmission to downshift when the throttle plate is wide open. If the transmission is in 2nd, it will downshift to 1st, and if the transmission is in 3rd gear, it will downshift into either 2nd or 1st, depending upon the speed of the vehicle. T.V. pressure and governor line pressure act on the 1-2 and 2-3 shift valves, which determine when the transmission shifts. When the kickdown valve is fully depressed, it allows T.V. pressure to act on a separate section of these valves, causing the downshift.

Figure 5-7 shows a simplified schematic of the fluid circuit in the valve body containing the kickdown valve, from a 1974 transmission which is basically the same as the 1978 model. The valves in this valve body have nearly identical functions as the valves in the 1982 valve body (the schematic of which is shown in Figure 5-4), but are placed in a different order in the fluid circuit. The only difference is that the T.V. limit valve is placed after the throttle valve, rather than before it as in the 1982 valve body. This means that the function of the T.V. limit valve is different, and that it acts as a relief valve allowing fluid to escape whenever the pressure exceeds 85 psi. Under normal operating conditions, this has no effect on the operation of the transmission. It should be noted that it is likely that similar kinds of variations probably exist for the same model transmissions made at different times, and that these variations may not coincide with different model years. The control arrangement used in the Audi transmission is typical of automatic transmissions on recent model cars, both domestic and imported, with the main variation perhaps being the order of the valves within the corresponding fluid circuit.

5.4.1 Kickdown Valve Operation and Failure Modes

Due to the manner in which the kickdown valve holds the kickdown lever captive in the 1983 and earlier transmissions, it is possible for the kickdown valve to operate the engine throttle by pulling on the kickdown lever. The following is a more detailed description of the kickdown valve, along with a discussion of possible failure modes and their side effects.

5.4.2 Kickdown Valve Operation

Figure 5-8 shows a detailed schematic of the fluid path in the 1982 valve body and Figure 5-9 shows an enlargement of the fluid path about the kickdown valve and the throttle valve. During normal operation, the kickdown valve is depressed by the kickdown lever and in turn presses on the throttle valve through the spring. T.V. pressure acts on the face of the kickdown valve and on the right face of the throttle valve. T.V. feed pressure acts in the chamber between the left and center faces of the throttle valve. The net pressure force acts to push the valve out against the kickdown lever, and this force increases as the throttle valve is depressed. Figure 5-10(a) shows a free body diagram of the external forces acting on the throttle valve and the kickdown valve. The T.V. feed pressure, acting in the chamber between the right and center faces of the throttle valve, exerts no net force on the valve assembly because the pressure in the chamber is the same throughout, and the area that the pressure acts on is the same on both the left and the right side of the chamber. T.V. pressure acts on both the

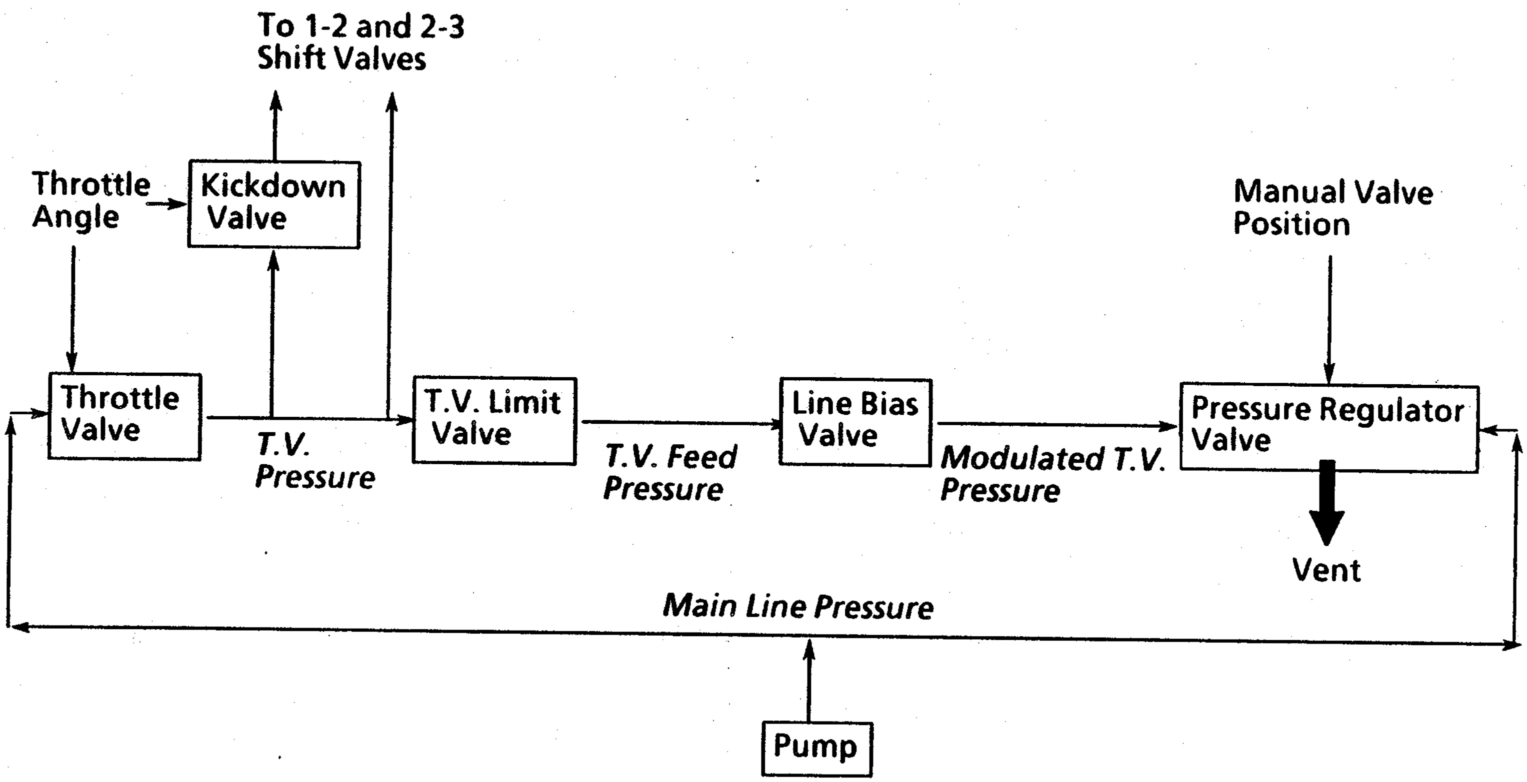
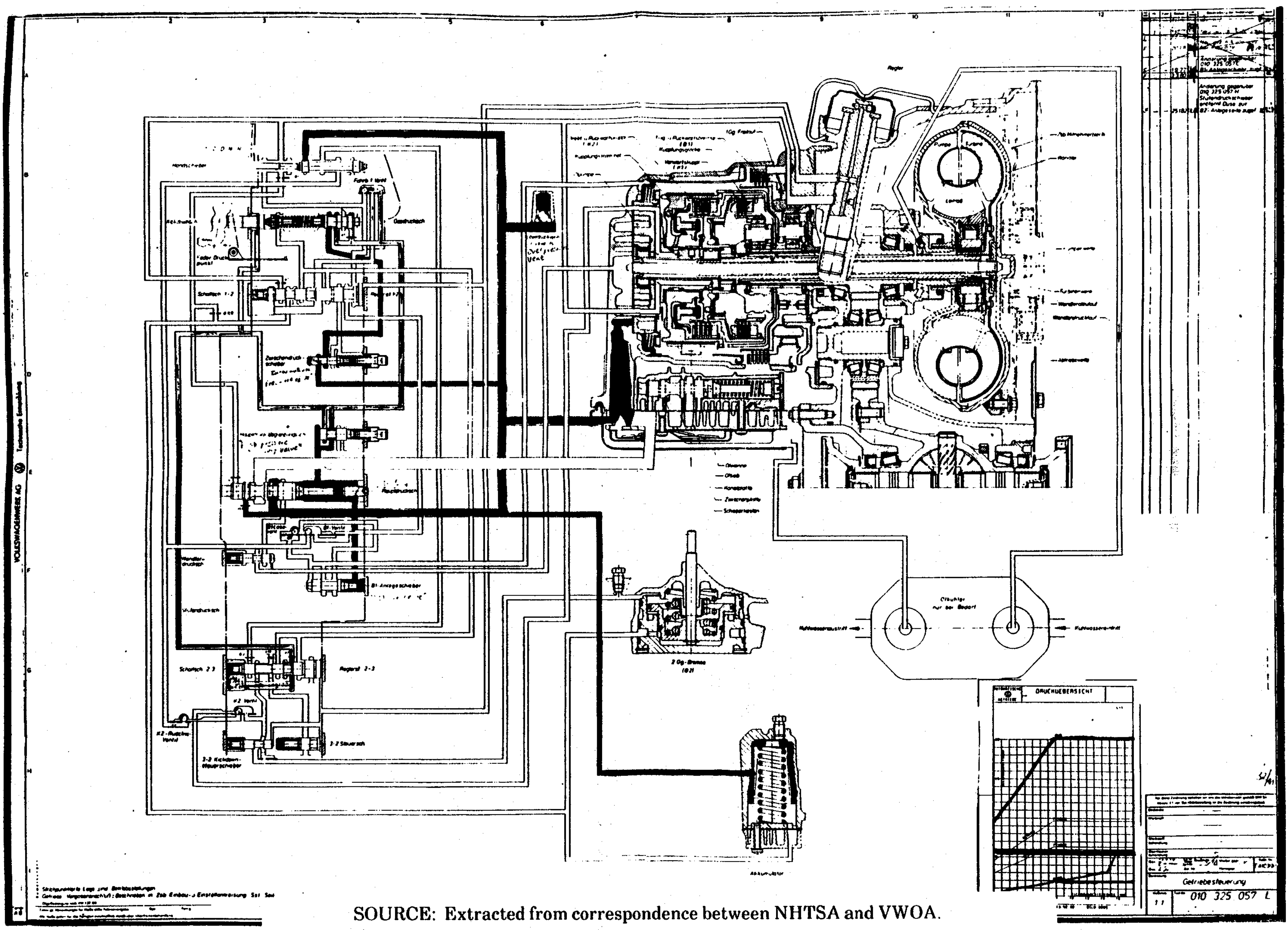
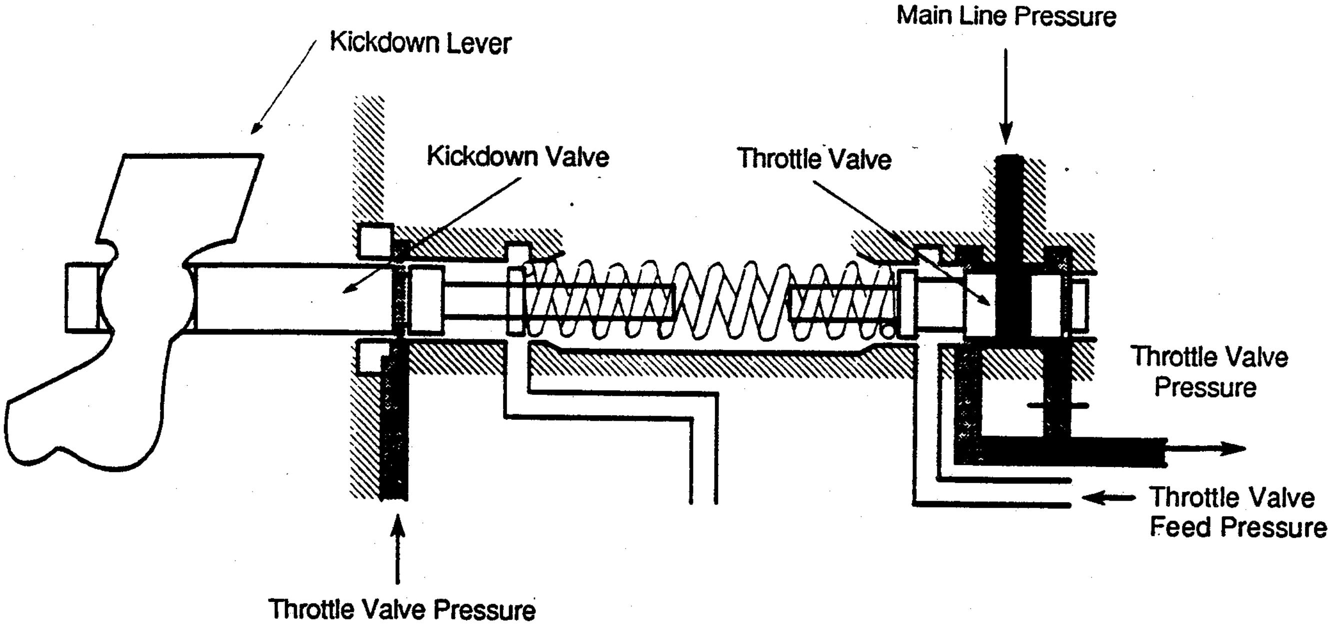


FIGURE 5-7. SIMPLIFIED SCHEMATIC OF THE 1974-82 KICKDOWN VALVE CIRCUIT

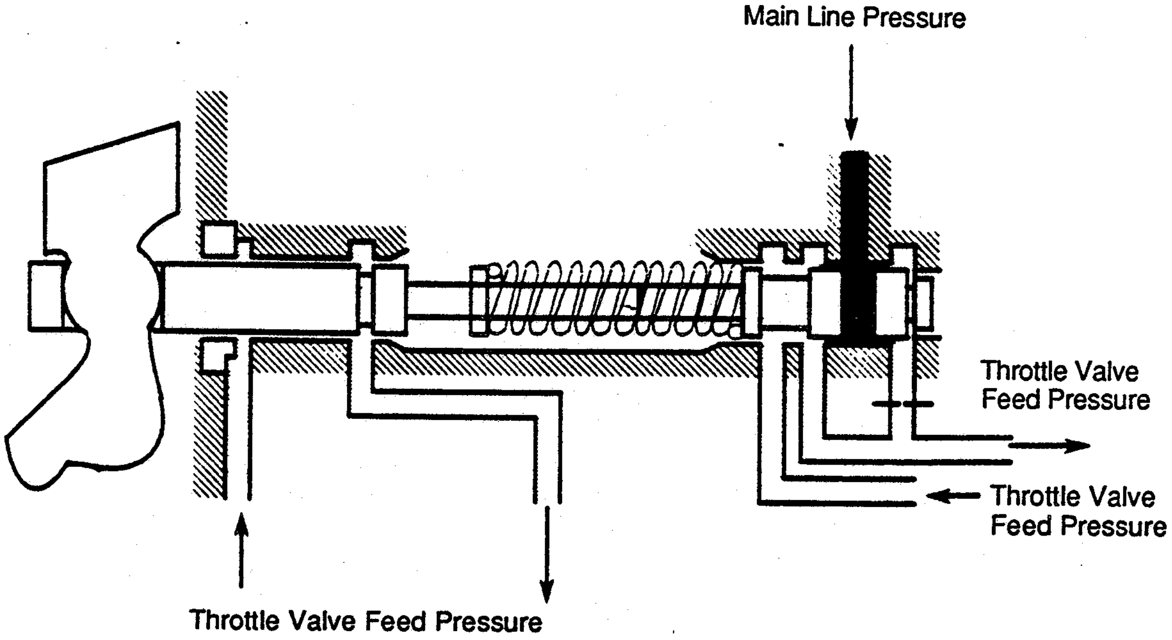


SOURCE: Extracted from correspondence between NHTSA and VWOA.

FIGURE 5-8. DETAILED SCHEMATIC FLUID PATH FOR THE 1982 TRANSMISSION



Kickdown valve fully extended (idle condition)



Kickdown valve fully depressed (full throttle condition)

FIGURE 5-9. KICKDOWN VALVE SCHEMATIC UNDER IDLE AND FULL THROTTLE POSITION

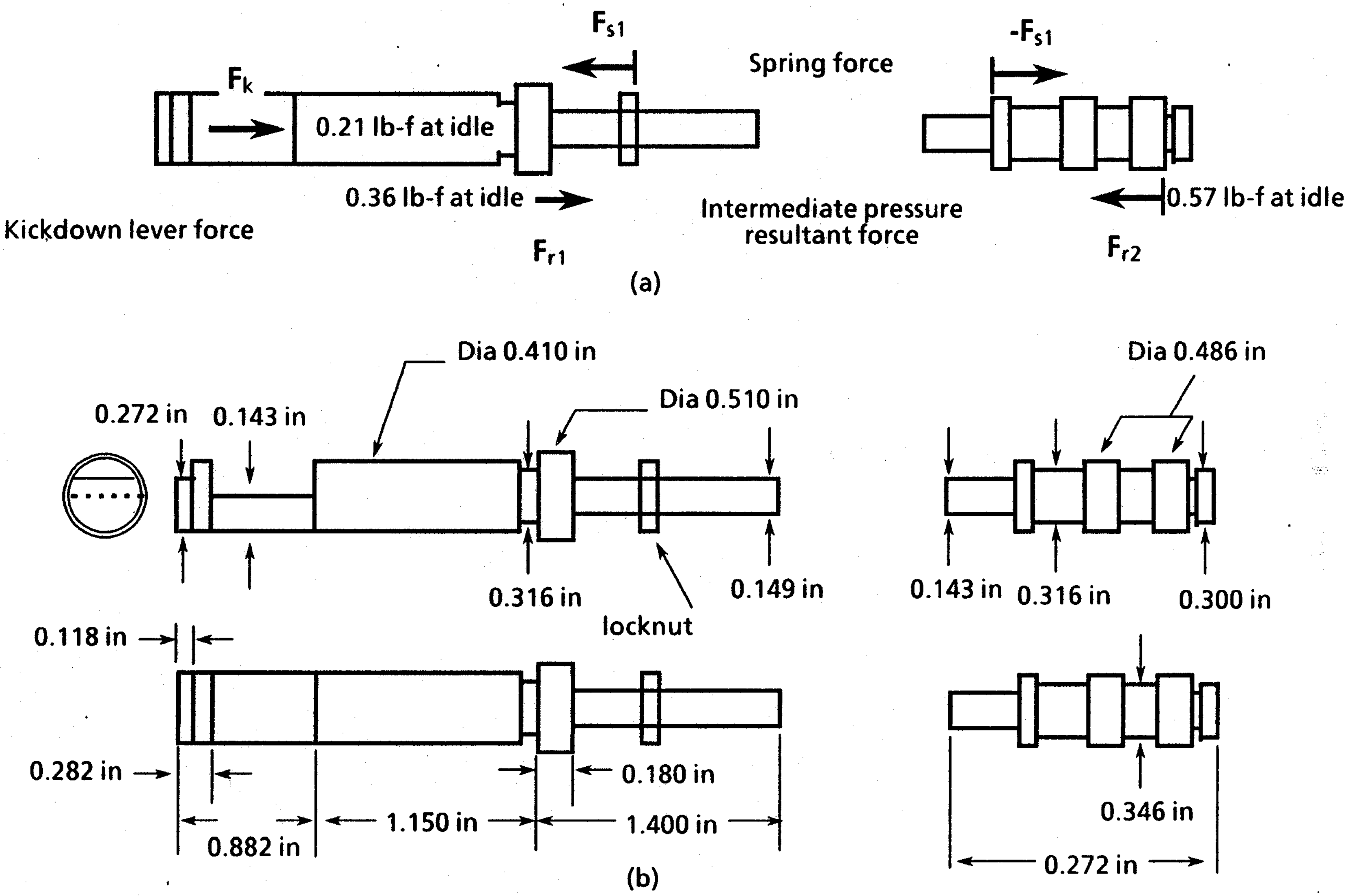


FIGURE 5-10. FREE BODY DIAGRAM AND KICKDOWN VALVE DIMENSIONS FOR A 1982 TRANSMISSION

face of the kickdown valve and the right face (in the figure) of the throttle valve, but the area that the pressure acts on is greater at the throttle valve, resulting in a net force acting to push this assembly out toward the kickdown lever. This force increases with T.V. pressure which, in turn, increases with increasing throttle angle, as described above. The net pressure force is balanced by the force exerted by the kickdown lever.

5.4.3 Failure Modes

Since the net pressure force acts to push the throttle valve outward (closing the throttle plate) under normal operating conditions, a malfunction must occur which results in the throttle valve being pulled inward. The throttle valve would have to become unable to resist the force resulting from the T.V. pressure acting on the kickdown valve. This could happen in two different ways: the throttle valve could stick in its bore, or the T.V. pressure could somehow be constricted or unable to act on the right face of the throttle valve.

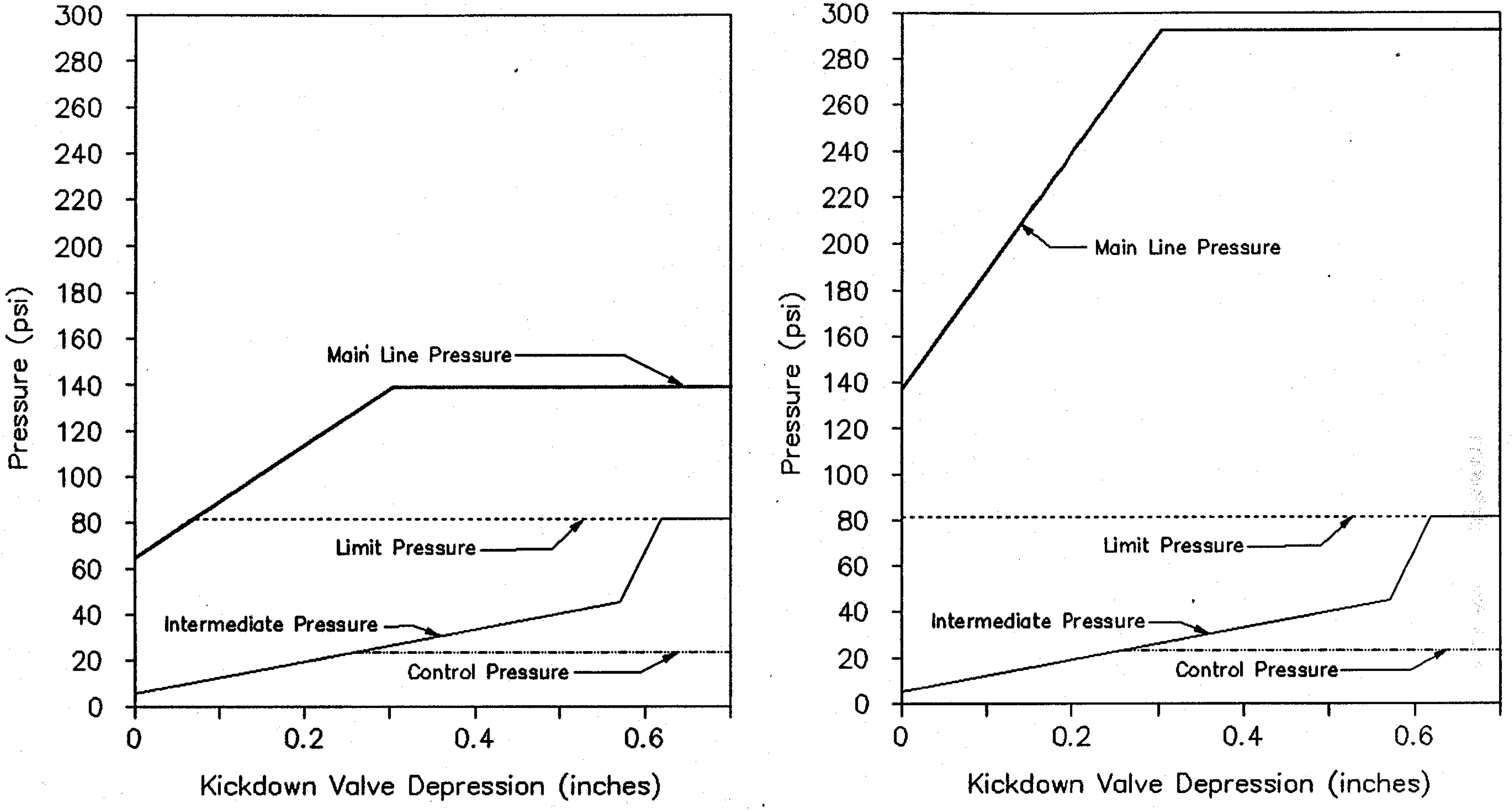
5.4.4 Stuck Valve

If the throttle valve were to stick in its bore, the transmission could malfunction in several different ways. Normally, the throttle valve produces T.V. pressure based upon the engine throttle opening. With the valve stuck in its bore, however, this pressure would no longer be dependent upon the throttle opening. (T.V. pressure is used by the shift valves to determine when the transmission shifts, and is used by the line bias and pressure regulator valves to determine line pressure.)

TSC has calculated that if the throttle valve was stuck in a position corresponding to its idle or near-idle position, T.V. pressure would be 5 psi, and the kickdown valve would be pulled in 0.028 in (5 psi acting on 0.072 sq in producing 0.36 lb-f, which would depress the spring between the throttle and kickdown valve, which has a stiffness of 12.7 lb/in by 0.028 in). As a result, the gear changes would occur at inappropriate times and the line pressure would remain independent of throttle position at 85 psi in drive or 140 psi in reverse. This would allow the clutches to slip if the car accelerated.

5.4.5 Inappropriate Pressure Applied to Kickdown Valve

The pressure required to depress the kickdown valve fully can be calculated based on the dimensions of the valve and the stiffness of the spring. The distance the spring travels from a relaxed to fully compressed position is 0.665 in; the spring stiffness is 12.7 lb/in. Figure 5-10(b) shows a dimensioned drawing of the kickdown valve. It takes 117 psi of pressure acting on 0.072 sq in to compress a 12.7 lb/in spring for 0.665 in. This pressure is the minimum necessary to depress the kickdown valve. It does not include the added resistance due to the external linkage, as the actual pressure necessary would be greater. During normal operating conditions, the pressure acting on the face of the kickdown valve never exceeds 85 psi. Figure 5-11 shows the pressure variations acting on the face of the kickdown valve, with T.V. pressure as a function of throttle angle depression, for both reverse and drive with the transmission engaged in 1st gear. This figure applies to both valve bodies discussed in the previous section. At idle, 5 psi acts on the face of the throttle valve while at wide-open throttle, 85 psi acts on the face of the valve.



Drive (1st Gear)

Reverse

SOURCE: Based on VWOA information from ODI.

FIGURE 5-11. KICKDOWN VALVE DEPRESSION/PRESSURE IN DRIVE AND REVERSE

Two types of failures within the valve body of the transmission could result in pressure exceeding 117 psi being applied to the face of the kickdown valve. A leak between channels could either cause line pressure to enter directly into the T.V. pressure channel, or cause a valve to function in an unintended fashion. In addition, it is possible for the pressure to increase at the face of the kickdown valve if one or more other valves in the valve body fail, allowing either line pressure directly into the T.V. pressure channel or a pressure change in another channel. Some combination of these two types of failures may also result in this increase in pressure. In all such cases, the throttle valve would have to be stuck in its bore or the T.V. pressure restricted from acting on the right face of the throttle valve.

Because of the size of the pressure channels in the transfer plate and valve body (ranging from approximately 0.100 to 0.310 in wide and 0.170 to 0.555 in deep), it would be difficult for a blockage to occur. If sufficient debris were able to accumulate, there would either be some evidence when the transmission was disassembled, or other difficulties within the transmission, such as stuck valves would be detected. Furthermore, if a constriction or blockage of T.V. pressure to the throttle valve were to occur, it would be more likely to take place in the separation plate. The feed hole to the throttle valve in the separation plate has a diameter of 0.087 in, and is more easily constricted than a pressure channel.

If T.V. pressure were not allowed to act on the right face of the throttle valve, an unstable situation would result. With no T.V. pressure to balance the spring force, the throttle valve would move to the right, allowing T.V. limit pressure into the T.V. pressure channel. This would cause the kickdown valve to displace 0.211 in, which would open the throttle approximately 31 percent in 1983 and earlier models. In addition, the line pressure would increase to its maximum (130 psi in drive, 300 psi in reverse), and the gear shifts would occur at inappropriate times.

5.5 CONCLUSIONS

In the Audi 5000 from 1978 through 1983, the transmission could conceivably activate the linkage and throttle plate in a shift from drive into neutral, reverse, or park. In these models, the throttle plate could be opened by an unbalanced pressure of at least 117 psi on the kickdown valve. An SAI due to transmission activation of the throttle would require multiple failures, would be irreversible, and would be easily detected after the fact. No evidence of such failures was found in vehicles exhibiting SAIs by TSC or ODI investigators.

6. BRAKE SYSTEM

6.1 INTRODUCTION

After the onset of an SAI, the driver should be able to stop the vehicle by braking. Drivers of Audi 5000s involved in sudden acceleration report that the brake pedal was depressed but the vehicle did not stop. On the assumption that the drivers had properly applied the brakes, the brake system was evaluated to identify any system malfunction which would prevent the driver from stopping the car. Appendix C supplies mathematical justification of the discussion to follow.

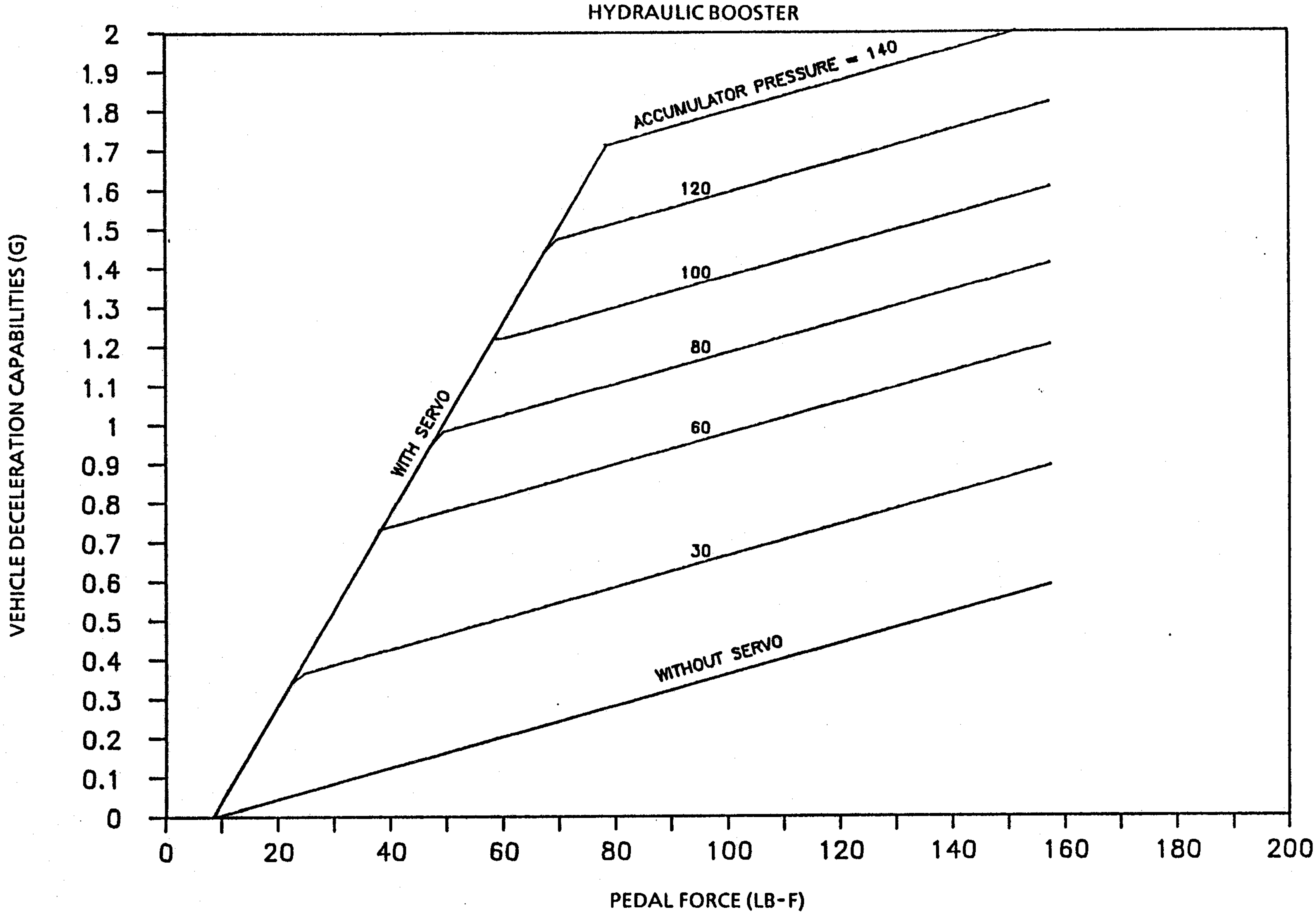
6.2 SYSTEM DESCRIPTION AND CHARACTERISTICS

The standard brake system on all Audi 5000s built after 1983 is a hydraulic disk brake system with a hydraulic power assist. The disk brake system consists of a master cylinder, hydraulic power assist, rear-brake pressure regulator, brake fluid lines, and four caliper brake assemblies. The hydraulic power assist consists of a central hydraulic pump, brake and steering fluid reservoir, a servo unit, and a hydraulic fluid accumulator. The hydraulic power assist reduces the amount of force the driver must apply to the brake pedal to decelerate the car. (Prior to 1984, a vacuum assist was used.) As shown in Figure 6-1, the pedal force required to produce 0.3 g of deceleration is 22.5 lb-f (100 N) with the power assist and 90 lb-f (400 N) without the power assist. The pedal forces required to hold an Audi stationary with a fully open idle stabilizer would be considerably smaller since it produces 0.3 g acceleration for only an instant.

Pressure in the power-assist system is developed in the central hydraulic pump, a constant displacement, eight-piston pump with two independent hydraulic circuits. Power steering is supplied by six of the pistons; fluid for the brake hydraulic assist is supplied by two pistons. The power steering and brake circuits are both supplied with hydraulic fluid from the same reservoir. The pump has a pressure-relief valve that bypasses the braking circuit when the pressure exceeds 155 bars. VWOA specifies that the valve should be replaced when it opens below 145 bars. Pumps are replaced when the flow rate is below 5 cc/sec at an engine speed of 850 RPM .

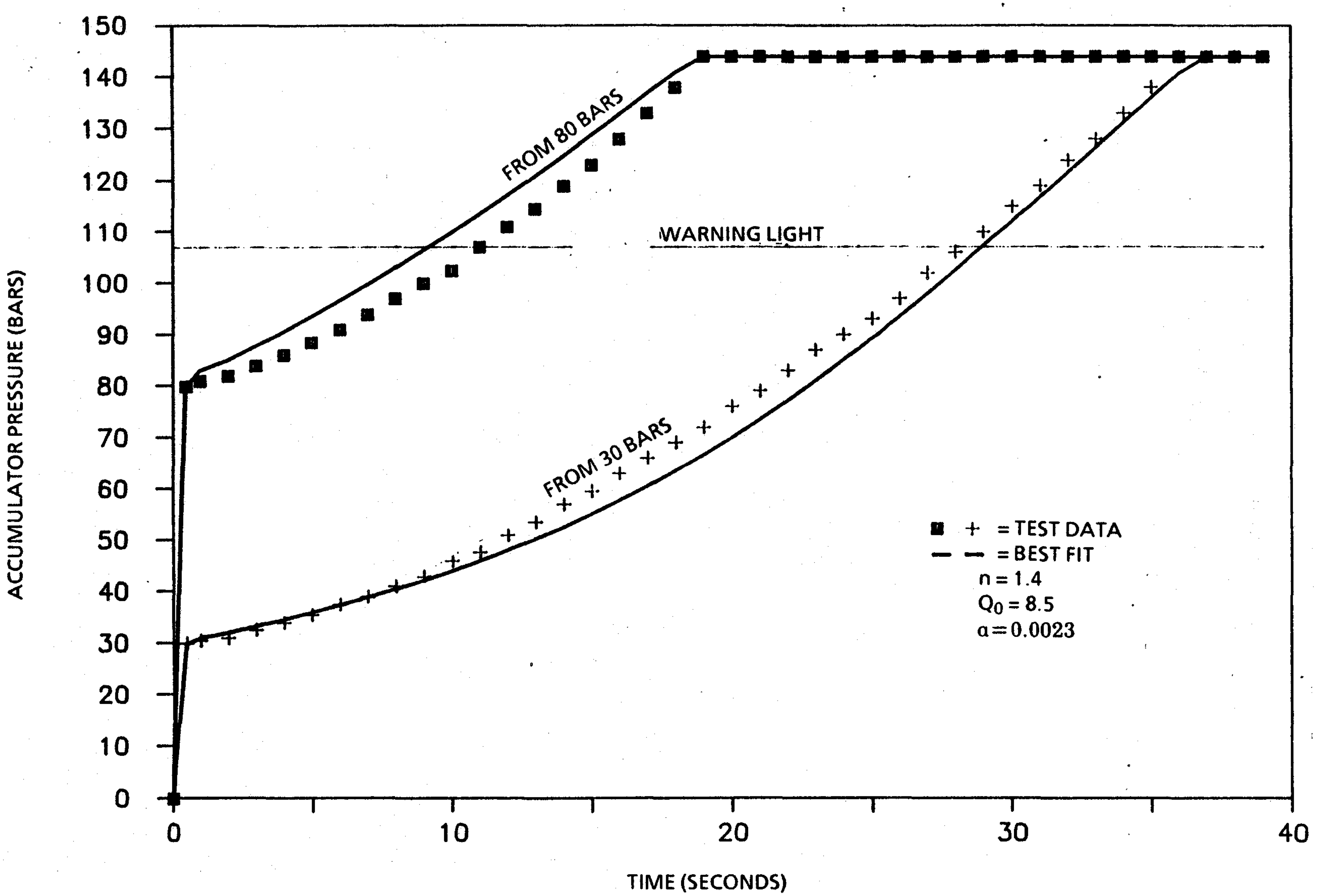
The pressure accumulator is a device which stores the pressurized hydraulic fluid to be used by the servo assist. The central hydraulic pump restores the fluid level and pressure in the accumulator. Without pump operation, enough fluid is stored in the accumulator for about 29 moderate brake applications that produce 0.22 g deceleration each. Each time the brake pedal is depressed, the servo assist draws pressurized fluid from the accumulator. Pumping the brake pedal requires a large volume of fluid. A pedal displacement of 0.79 in (20.1 mm) removes 0.27 in^3 (4.5 cm^3) of fluid from the accumulator and produces 0.20 bar (and produces about 0.22 g deceleration) of brake pressure. The servo assist uses this fluid during braking and then passes it at low pressure to the reservoir. A pressure-relief valve in the accumulator is designed to open at 150 bars when installed, and is replaced when it opens below 140 bars. The pump delivers fluid to the accumulator as long as pressure developed by the pump is greater than the pressure in the accumulator. When the fluid in the accumulator reaches full pressure, the relief valve operates continuously until pressure drops below designed accumulator pressure, allowing the hydraulic fluid delivered by the pump to drain to the reservoir.

Loading time of the accumulator is defined as the amount of time required to raise the pressure in the accumulator from the empty pressure to any specified pressure. The empty pressure is the accumulator gas pressure when there is no hydraulic fluid present in the accumulator. Test data in Figure 6-2, supplied by Audi, show the relationship between gas pressure versus time during loading of the accumulator from empty pressures of 30 and 80 bars. For these test results, it took 19 seconds to load the accumulator from 80 to 144 bars, and 36 seconds to load it from 30 to 144 bars.



SOURCE: Calculated by TSC based on VWOA data from ODI.

FIGURE 6-1. VEHICLE DECELERATION VERSUS PEDAL FORCE



SOURCE: Calculated by TSC based on VWOA data from ODI.

FIGURE 6-2. LOADING TIME FOR BRAKE ACCUMULATOR

6.3 POSSIBLE MALFUNCTIONS

After the onset of an SAI, the driver should be able to control the vehicle by braking. The severity of the event depends on the driver's reaction and the brake system's condition. A total brake system failure would be obvious after an incident. In order for the system to completely fail, the hydraulic brake fluid must leak internally to the master cylinder or leak into the environment. In such a closed hydraulic system, evidence of a failure would remain. A low fluid level in the brake fluid reservoir would indicate a leak somewhere in the system. When the master cylinder leaks internally, the failure is almost always permanent and the brake system continues to be inoperable after the incident.

The brake system is capable of a temporary malfunction of the hydraulic power assist. If the power-assist system malfunctioned, the required brake-pedal pressure would be about 4.6 times the normal (assist working) required braking force. Though this would make the system seemingly unresponsive, it could, with enough force, still stop the vehicle.

6.4 HYDRAULIC ASSIST MALFUNCTION AND RECOVERY

A temporary failure of the hydraulic assist is possible. If the brake accumulator was drained fully on start-up and the driver immediately shifted the vehicle into gear and pumped the brake pedal faster than the central hydraulic pump could restore accumulator pressure, the assist would be inoperable (degraded). However, given time, the pump would restore the fluid level and pressure in the accumulator and the brake-assist system would operate normally.

6.5 EFFECTS OF A DRIVER OUTRACING THE HYDRAULIC PUMP

Drivers who have experienced sudden acceleration claim that the brake was inoperable during the incident but operated normally after the incident. During the incident, the driver can brake the car by depressing the brake continuously, or by rapidly pumping the brake pedal. Pumping the brake could decrease the braking effectiveness with every pedal stroke. For this to occur, the volume of fluid being used by the servo must be greater than the fluid delivered by the pump. Eventually the volume of fluid stored in the accumulator would decrease until the accumulator was empty, causing the power assist to become ineffective. To determine both the number of pedal strokes and the amount of time needed to produce this effect, it was assumed that the driver applied an average force of 100 lb-f to the brake pedal and depressed the brake pedal once every second. The pump delivery rate depends on the engine speed. The worse case for the pump would be at idle (850 RPM) for the lowest hydraulic fluid flow rate. The amount of fluid stored in the accumulator is related to the initial gas pressure. The lower the initial accumulator gas pressure, the more hydraulic fluid can be stored. A typical accumulator gas pressure is between 30 and 80 bars; the accumulator should be replaced when the gas pressure is below 30 bars. For an initial gas pressure of 80 bars with the engine at 850 RPM, it would take 18 seconds and 18 pedal depressions to drain a fully loaded accumulator.

After the accumulator is drained, brake effectiveness can be reduced depending on how much of each second is used in the motion of the pedal and how much is used to hold the pedal depressed. When the pedal is in motion, fluid is drawn from the accumulator; when the pedal is held stationary, fluid pressure builds in the accumulator. When the accumulator oscillates between fully drained and partially filled, theoretical brake deceleration capabilities can oscillate between 1.3 and 0.36 g. This would make the brakes feel operative during one depression and inoperative in the next, and would continue with each pedal depression. When the initial gas pressure of the accumulator is 30 bars, it takes over 60 seconds and 60 pedal depressions to get to the oscillation state. In these cases the engine speed is 850 RPM. If the engine RPM exceeds 1000, the volume of fluid being used by the servo is less than the fluid delivered, making it very difficult to outrace the hydraulic pump. In the case of a sudden acceleration, the engine must produce enough power to move the vehicle, and would most likely maintain an engine speed greater than 1000 RPM.

To outrace the pump, the driver would have to maintain a pedal-pumping rate of greater than two times per second with an average force of 100 lb-f for longer than 18 seconds. Pumping at this rate would provide a severe deceleration until the accumulator was depleted. However, even with the accumulator depleted, the application of this much force would stop the vehicle.

7. DIMENSIONS, SPECIFICATIONS, AND FORCES RELATIVE TO THE AUDI DRIVING ENVIRONMENT

7.1 OBJECTIVE AND APPROACH

The overall objective of this section is to identify driver-related factors that may contribute to or cause driver errors and thereby produce SAIs. Two categories of driver-related factors are examined:

- the physical arrangement of the Audi driving compartment, including seats and pedals
- the characteristics which discriminate the Audi driver (especially those included in NHTSA's sudden acceleration complaint file) from drivers in general

In this section statistical comparisons are made between physical measurements of the Audi driver's environment and measurements of the U.S. passenger car fleet, and between the characteristics of the Audi driver and nondifferentiated U.S. drivers. Correlations are on a fleet basis.

The Audi driving environment examined includes both the seating dimensions and the pedal arrangements, measurements, and forces. Driver comparisons are made on the basis of age, sex, height, income, accident record, experience, and exposure (i.e., vehicle miles of travel per time unit). These comparisons rely extensively on available dimensional data from vehicle manufacturers, information provided by Audi, TSC measurements, two accident databases (the National Accident Sampling System [NASS] and the Crash Avoidance Research Data File [CARDfile]), and survey data from the National Personal Transportation Study (NPTS).

7.2 THE AUDI DRIVING ENVIRONMENT

It can be hypothesized that a particular vehicle may have a relatively high frequency of reported errors for new drivers because the vehicle has a physical driving configuration which is substantially different from previously driven vehicles. Studies by NHTSA (Perel 1983) and TSC (Hoxie 1984) have indicated that driver unfamiliarity with a vehicle substantially increases the probability of accidents. As noted below, the Audi 5000's SAIs occur early in the ownership cycle. In order to explore whether drivers may have found the Audi's driving configuration unfamiliar, thereby increasing the likelihood of errors, comparisons were made between the Audi 5000 and other vehicles' dimensions, specifications, and forces relating to the seating and pedal arrangements.

Dimensions used for the seating comparisons are derived from the Society of Automotive Engineers Recommended Practice J1100, Motor Vehicle Dimensions. This practice defines a uniform set of interior and exterior dimensions for passenger cars. All dimensions are defined normal to a three-dimensional reference system. Each dimension is assigned an alphanumeric code which is composed of a prefix letter denoting the direction (W - width, H - height, and L - length) and a sequence number. J1100 defines each of these dimensions and how they are to be measured. The interior measurements of interest here are defined with the adjustable front seat in its rearmost normal driving position resulting in the H-point (pivot center for the torso and thigh) being positioned at the seating reference point (SgRP). This SgRP is usually one notch forward from the most rearward position. The manufacturer uses either an H-point machine (a three-dimensional stick-like dummy) or a two-dimensional drafting template. In both cases, the machine or template is set to the 95th percentile leg segments as specified in SAE Recommended Practice J826b. Dimensional comparisons, therefore, are based on the same criteria.

TSC has available, in a computerized database, complete dimensional data for all GM makes, models, and body lines from 1975 through 1983. Identical but less extensive data were also available for approximately 5,000 domestic and imported vehicles from 1965 to 1975 and any vehicle with 10,000 or more registrations in model years 1975, 1979, or 1980 (100 to 150 vehicles per model year). Identical data were provided by Audi for their 5000 model in two sets: 1978 through 1983 and 1984 through 1986.

TSC determined the means, standard deviations, and maximum and minimum values for the available dimensional data, and compared them to the same measurements provided by Audi. These comparisons were made using the "T" value, which is the dimension from the Audi (or similar vehicle) minus the mean of the same measurement from the data set to which the Audi is being compared, divided by its standard deviation.

In addition to the aggregated dimensions of the U.S. fleet, the Audi dimensions were compared to those of three 1983 Cadillac models whose dimensions were available in the TSC database. These vehicles were three 1983 Cadillac models selected under the assumption that they would be purchased by buyers from the same economic strata and could represent the type of vehicle the Audi purchasers may be accustomed to driving.

Table 7-1 shows comparisons for the data describing the two Audi models with GM aggregated dimensional data and data for the three Cadillac models (the Cimarron, a small, front-wheel-drive "European-type" road car based on the J-body line; the Eldorado, a front-wheel-drive luxury coupe; and the DeVille, a large, rear-wheel-drive luxury sedan).

In the T tables (Figures 7-1 and 7-2), the two Audi model-year groups and three Cadillacs are compared to all GM models. (These GM models represent approximately 50 percent of the automobiles on the road in the U.S.)

The T values show that of the 25 seating attributes that were compared, only 5 attributes of the 1978 to 1983 Audis and 7 of the 1984 to 1986 Audis were within 1 standard deviation of the mean of all GM vehicles,* whereas 50 to 75 percent of the Cadillac seating attributes, depending on the model, were within 1 standard deviation. Six Cadillac measurements were outside of two standard deviations, whereas ten Audi measurements were three to five standard deviations from the mean. Among Cadillacs, the Cimarron is the closest to the Audi, whereas the DeVille is the farthest. The DeVille is the best fit to the overall GM data.

With respect to individual measurements:

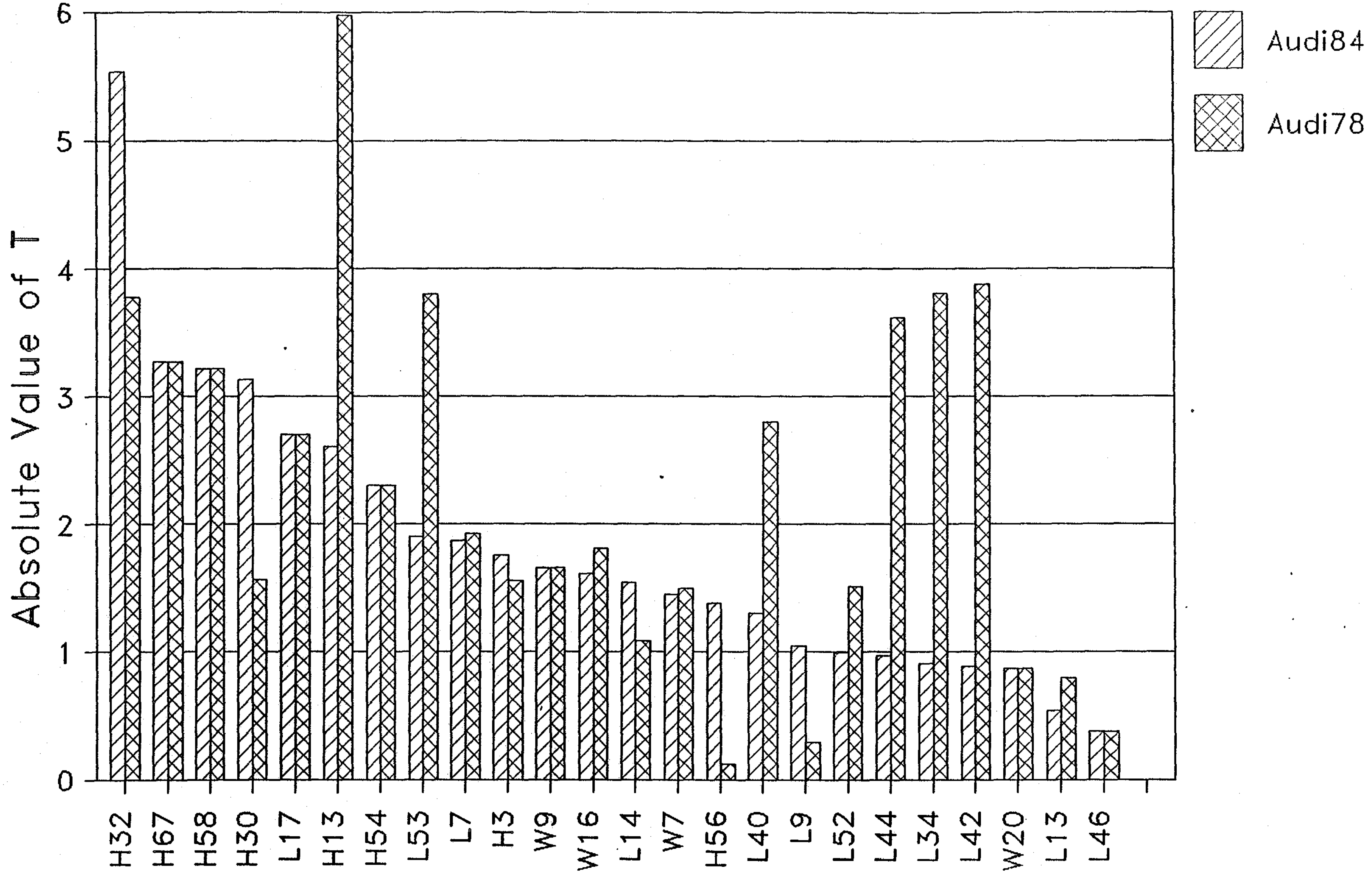
- The seat in the Audi is much harder than in the standard GM vehicle (H32).
- The Audi floor covering is much thicker (H67).
- The Audi seat has less rise (H58) than the standard GM seat when adjusted from the rearmost seating position to the foremost. The Audi seat is significantly higher than the standard GM seat, but when moved forward to accommodate a smaller driver, the seat rises less than a standard GM seat.
- The hip angle (L42) of the 1978 to 1983 Audi is much greater than the aggregate.

Assuming the data are normally distributed, a measurement which is more than one standard deviation from the mean is either larger or smaller than 84 percent of all the measurements on which the mean is based. A measurement two standard deviations from this mean is larger or smaller than 97 percent of the cases.

TABLE 7-1. COMPARISON OF GM FLEET AND SELECTED AUDI AND CADILLAC DIMENSIONS

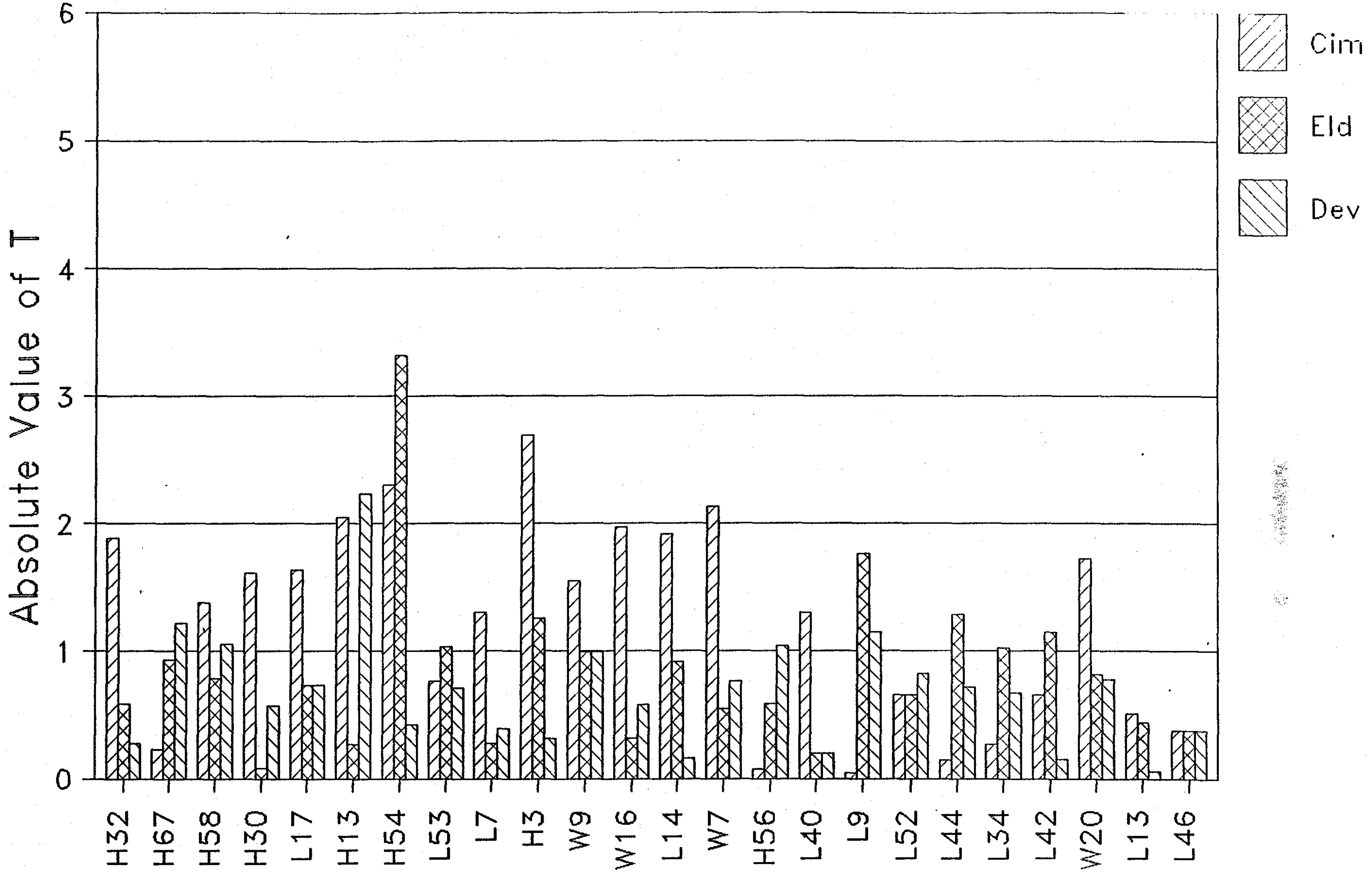
SAE	DIMENSION	G.M.		CADILLACS			AUDIS		T VALUES			T VALUES	
		Mean	δ	Cim	Eld	Dev	Audi 84	Audi 78	Cim	Eld	Dev	Audi 84	Audi 78
H32	Seat Cushion Deflection	83.7	9.7	102.0	78.0	81.0	30.0	47.0	1.89	-.59	-.28	-5.54	-3.78
H67	Floor Covering Thickness	14.4	6.9	16.0	8.0	6.0	37.0	37.0	.23	-.93	-1.22	3.28	3.28
H58	H-Point Rise	22.9	3.7	28.0	20.0	19.0	11.0	11.0	1.38	-.78	-1.05	-3.22	-3.22
H30	H-Point to Heel Point	219.0	23.0	256.0	217.0	232.0	291.0	255.0	1.61	-.09	.57	3.13	1.57
L17	H-Point Travel	155.4	22.4	192.0	139.0	139.0	216.0	216.0	1.63	-.73	-.73	2.71	2.71
H13	Seat Wh. to Center Thigh	93.9	10.7	72.0	91.0	70.0	66.0	30.0	-2.05	-.27	-2.23	-2.61	-5.97
H54	D-Point to Tunnel	54.1	23.5		132.0	64.0			-2.30	3.31	.42	-2.30	-2.30
L53	H-Point to Heel Point	880.0	18.4	866.0	899.0	867.0	845.0	810.0	-.76	1.03	-.71	-1.90	-3.80
L7	Steering-Wheel Torso Clearance	345.1	17.6	368.0	350.0	352.0	378.0	379.0	1.30	.28	.39	1.87	1.93
H3	Seat Chair Height	275.6	20.2	330.0	301.0	282.0	311.0	307.0	2.69	1.26	.32	1.75	1.55
W9	Steering-Wheel Diameter	385.1	9.0	399.0	394.0	394.0	400.0	400.0	1.54	.99	.99	1.66	1.66
W16	Seat Width	1156.9	327.6	512.0	1259.0	1347.0	630.0	565.0	-1.97	.31	.58	-1.61	-1.81
L14	Seat Thickness at Center	151.3	28.8	96.0	125.0	156.0	107.0	120.0	-1.92	-.91	.16	-1.54	-1.09
W7	Steering-Wheel. Cent. to Cent. Car	377.1	31.5	310.0	360.0	401.0	331.6	330.0	-2.13	-.54	.76	-1.44	-1.50
H56	D-Point to Floor	157.1	23.9	159.0	171.0	182.0	190.0	160.0	.08	.58	1.04	1.38	.12
L40	Back Angle	26.3	1.0	25.0	26.5	26.5	25.0	23.5	-1.30	.20	.20	-1.30	-2.80
L9	Seat Depth	491.7	30.2	493.0	545.0	457.0	460.0	483.0	.04	1.76	-1.15	-1.05	-.29
L52	Brake Pedal to Accelerator	81.1	29.3	62.0	62.0	57.0	52.0	37.0	-.65	-.65	-.82	-.99	-1.51
L44	Knee Angle	128.0	3.5	127.5	132.5	125.5	124.6	115.3	-.14	1.29	-.71	-.97	-3.62
L34	Max. Eff. Leg Room Accel.	1075.3	12.4	1072.0	1088.0	1067.0	1064.0	1028.0	-.27	1.02	-.67	-.91	-3.81
L42	Hip Angle	97.2	2.0	98.5	99.5	97.5	99.0	89.4	65	1.15	.15	.89	-3.88
W20	Center Occup. to Center Car	366.4	18.8	334.0	351.0	381.0	350.0	350.0	-1.72	-.82	.78	-.87	-.87
[illegible]13	Brake-Pedal Knee Clearance	617.0	31.7	601.0	631.0	619.0	600.0	592.0	-.50	.44	.06	-.54	-.79
L46	Foot Angle	87.6	1.6	87.0	87.0	87.0	87.0	87.0	-.38	-.38	-.38	-.38	-.38
H18	Steering-Wheel Angle Vertical			20.0	18.3	19.0	21.4	20.2					

Cim = Cadillac Cimarron
Eld = Cadillac Eldorado
Dev = Cadillac Coup DeVille



SAE Dimensions as Described in Table 7-1

FIGURE 7-1. T TABLE FOR AUDI



SAE Dimensions as Described in Table 7-1

FIGURE 7-2. T TABLE FOR CADILLAC

- The maximum effective leg room to the accelerator (L34) of the 1984 to 1986 Audi is within 1 standard deviation of the GM mean, but that of the 1978 to 1983 Audi is significantly different (3.8 T).

- The steering wheel (nonadjustable in the Audi) is also closer to the centerline of the thigh in the Audi than in a standard GM vehicle (H13).

Table 7-2 compares a limited number of the Audi interior dimensions to other available databases. The first three sections of the table compiled by TSC (VEH 75, 79, and 80) compare the Audi to over 100 of the most popular domestic and imported vehicles in each of those model years. In the VWATTS table, the same Audi dimensions are compared to 4,000 1965 through 1975 domestic and foreign vehicles. Of interest is the similarity between the VWATTS and the VEH 75, 79, and 80 derived means from year to year, and to the previously discussed GM data.

The only dimension in these sets that appears to change with time is the H-point travel (longitudinal seat travel), which has increased from a mean of 129.5 mm in the VWATTS (1965 to 1975) to 154.9 mm in the 1980 database. The Audi's H-point travel is 215.9 mm. It is interesting to note that the smaller cars appear to have a longer seat travel. (GM's post-1980 front-wheel-drive J-, X-, A-, and F-body lines have a seat travel of 190 mm.) This probably reflects a need to make the smaller cars more accommodating.

As most Audi 5000s have eight-way adjustable power seats, the seating arrangement was further investigated by using three individuals who approximated a 5th percentile female (59.5 in height), a 50th percentile male (68.8 in), and a 95th percentile male (73.2 in.). The subjects were instructed to adjust the seat to a comfortable driving position and drive the vehicle to confirm or readjust their selection. The subjects were photographed (Figures 7- 3 through 7-5) and their comments solicited. The 5th and 50th percentile subjects described their seating accommodation as very comfortable ("one of the best ever encountered"). The 95th percentile subject found that leg and knee room was limited, even with the seat in its most rearward position. This subject also felt that this could affect the pedal activation.

Although these three subjects found the car to be accommodating, other Audi owners and drivers contacted commented on the fact that the steering-wheel and seat centerlines were displaced, with the steering wheel being to the right of the center of the seat.

Table 7-3 shows pedal dimensions, and the driver's lateral placement with respect to the steering wheel. For 31 1983 through 1987 vehicles, examples of these measurements for individual vehicles can be found in Appendices E and F. In Appendix E, the data are presented from 84 1973 through 1981 domestic vehicles. Appendix F provides data for 75 1982 through 1985 vehicles.

These data are combined and compared using the T value in Figures 7-6 through 7-8. They indicate that significant changes have taken place in pedal dimensions and arrangements from 1975 to 1987. As can be seen in Table 7-4, these differences are more evident in the means for each of the previously mentioned data sets. (The Cadillac comparisons were used for the reasons noted above.) These trends indicate that the right side of the brake pedal has been moved further to the right in relation to the steering wheel; the brake pedal is also slightly narrower, and its length is increasing. In addition, there appears to be a slight increase in accelerator-pedal width and a significant decrease in its length. The distance from the accelerator pedal to the center floor hump is increasing, reflecting downsizing and the switch to front-wheel drive. (In fact, in some vehicles, the center hump is no longer evident.) This can be seen in a comparison of 1979 and 1985 Cadillacs.

TABLE 7-2. COMPARISON OF OTHER INTERIOR DIMENSIONAL DATABASES TO THE AUDI

Database and SAE Designation	Dimension	#of Cases	Mean	SD	Min.	Max.	Audi 1984
VEH75							
L34	Maximum Effective Leg Room Accelerator	117	1066.8	22.9	975.4	1120.1	1061.7
H30	H-Point to Heel Point	106	210.8	17.8	154.9	276.9	289.6
L17	H-Point Travel	117	134.6	12.7	114.3	165.1	215.9
H1B	Steering-Wheel Angle Vertical	103	20.9	3.0	14.4	26.4	21.0
L40	Back Angle	110	26.1	0.9	24.0	33.0	25.0
VEH79							
L34	Maximum Effective Leg Room Accelerator	101	1069.3	25.4	1016.0	1115.1	1061.7
H30	H-Point to Heel Point	107	213.4	25.4	152.4	261.6	289.6
L17	H-Point Travel	106	144.8	20.3	76.2	190.5	215.9
H1B	Steering-Wheel Angle Vertical	107	22.4	7.1	15.0	46.8	21.0
L40	Back Angle	107	25.7	1.5	23.0	33.0	25.0
VEH80							
L34	Maximum Effective Leg Room Accelerator	92	1069.3	25.4	1000.8	1115.1	1061.7
H30	H-Point to Heel Point	91	223.5	27.9	154.9	279.4	289.6
L17	H-Point Travel	92	154.9	30.5	0.0	198.1	215.9
H1B	Steering-Wheel Angle Vertical	89	22.1	7.1	15.0	50.6	21.0
L40	Back Angle	90	25.7	1.1	24.0	33.0	25.0
VWATTS							
L34	Maximum Effective Leg Room Accelerator	4166	1069.3	17.3	591.8	1160.0	1061.7
H30	H-Point to Heel Point	3872	215.9	15.2	96.5	287.0	289.6
L17	H-Point Travel	3227	129.5	12.7	96.5	248.9	215.9
H1B	Steering-Wheel Angle Vertical	817	21.6	2.7	14.3	59.6	21.0
L40	Back Angle	843	26.1	9.4	0.2	97.0	25.0

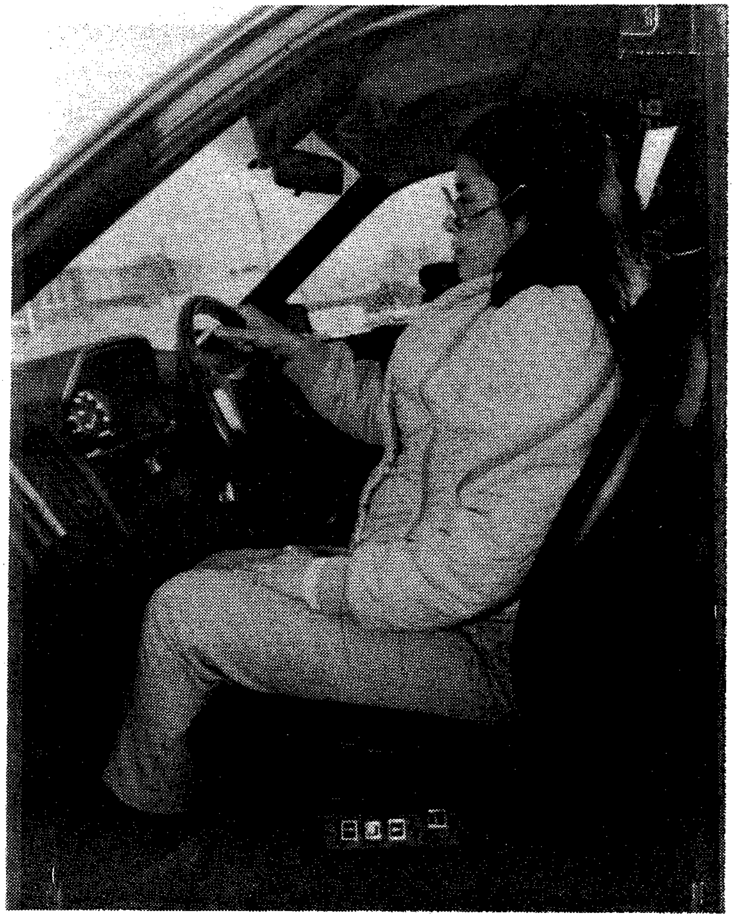


FIGURE 7-3. 5TH PERCENTILE FEMALE (59.5 IN) IN AUDI DRIVER'S SEAT

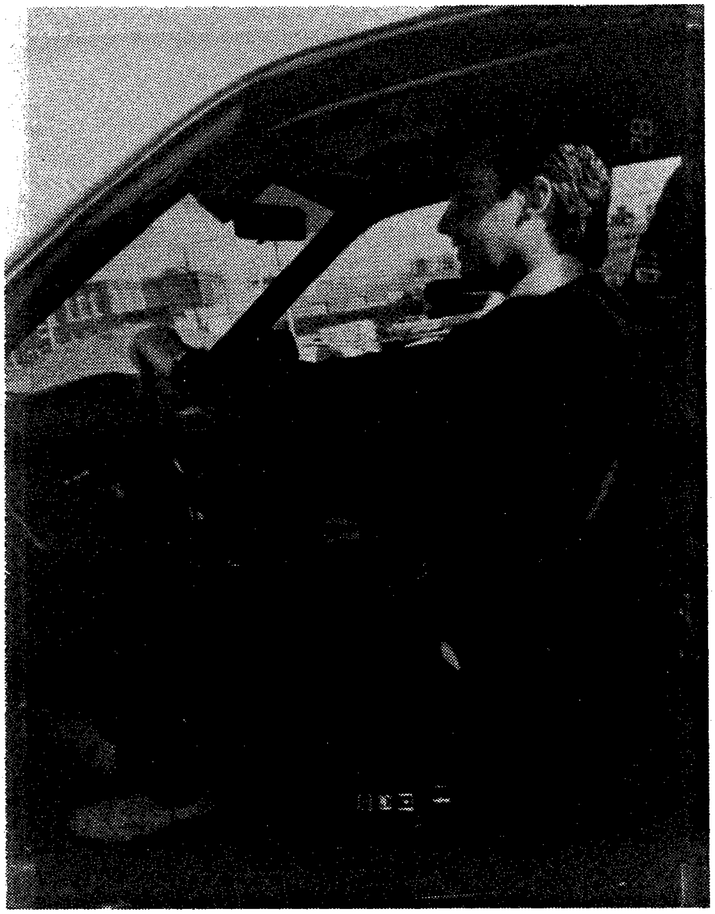


FIGURE 7-4. 50TH PERCENTILE MALE (68.8 IN) IN AUDI DRIVER'S SEAT

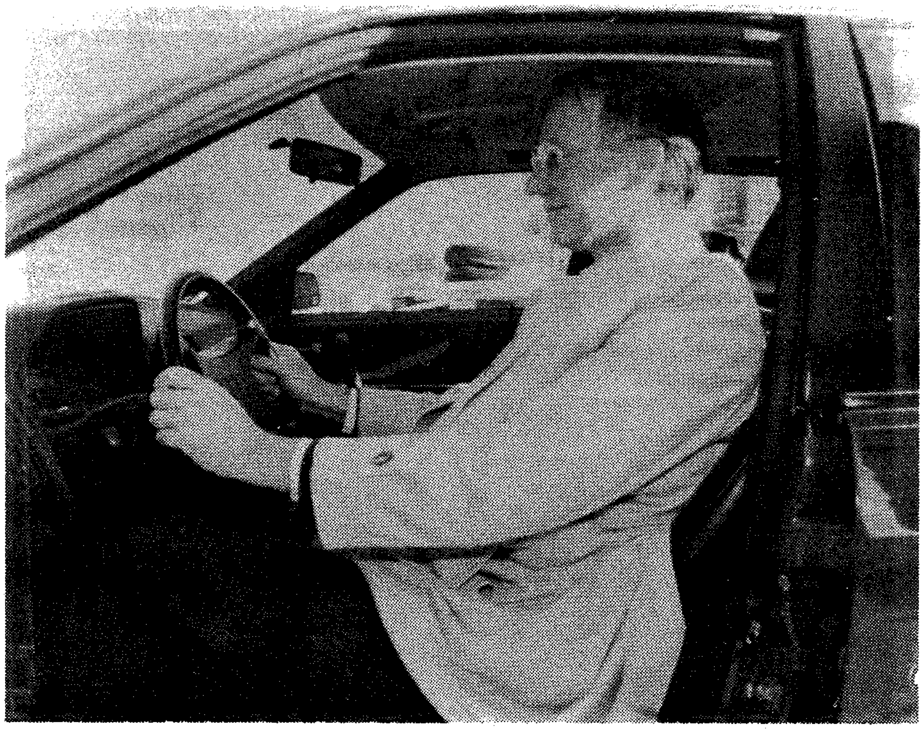


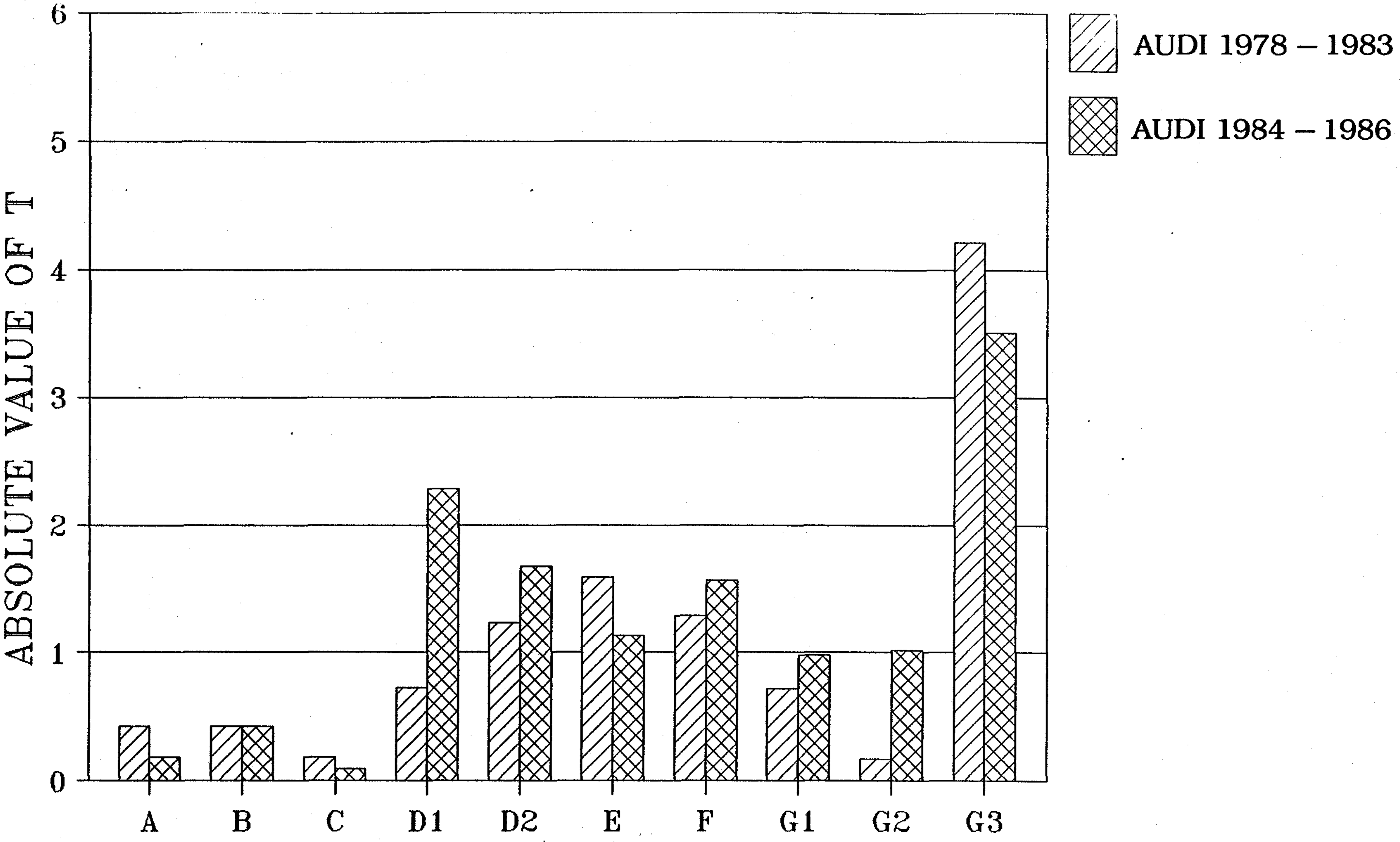
FIGURE 7-5. 95TH PERCENTILE MALE (73.2 IN) IN AUDI DRIVER'S SEAT

TABLE 7-3. PEDAL DIMENSIONS AND DRIVER'S LATERAL PLACEMENT (mm)

MAKE/MODEL		YR	C1T	C1B	E2	F3	X4T	X4B	X12	A13
PONTIAC	GRAND AM	85	47.63	57.15	127.00	63.50	111.13	120.65	31.75	122.24
ISUZU	IMPULSE	83	49.21	49.21	146.05	66.68	107.95	107.95	-6.35	12.70
FORD	MUSTANG	84	31.75	31.75	136.53	50.80	82.55	66.68	-4.76	45.40
CADILLAC	COUPE DEVILLE	87	50.80	60.33	130.18	53.98	136.53	120.65	-14.29	90.49
CHRYSLER	LEBARRON GTS TURBO	87	44.45	53.98	111.13	60.33	139.70	139.70	3.18	66.68
DODGE	LANCER	87	50.80	50.80	107.95	60.33	142.88	142.88	.00	79.38
BUICK	ELECTRA SEDAN	86	50.80	57.15	130.18	50.80	130.18	120.65	-28.58	102.33
CHEVROLET	CELEBRITY WAGON	86	57.15	69.85	133.35	57.15	139.70	107.95	.00	109.47
SABLE	GS WAGON	87	63.50	69.85	133.35	73.03	120.65	120.65	6.35	92.08
PONTIAC	FIERO	85	50.80	57.15	127.00	44.45	95.25	79.38	3.18	62.71
CHRYSLER	RELIANT WAGON	85	50.80	50.80	107.95	57.15	139.70	139.70	9.53	101.60
AUDI	5000S	85	46.04	46.04	117.48	66.68	101.60	76.20	12.70	31.75
VW	QUANTUM GLS	87	47.63	47.63	101.60	53.98	80.96	77.79	15.88	11.11
HONDA	ACCORD DX	87	50.80	53.98	119.06	69.85	149.23	130.18	15.88	110.11
FORD	LTD	86	30.16	30.16	146.05	60.33	101.60	85.73	-11.11	27.62
AUDI	5000CS TURBO	85	53.98	53.98	98.43	66.68	101.60	76.20	19.05	12.70
AUDI	4000S FUEL INJ	85	47.63	47.63	101.60	53.98	80.96	80.96	31.75	44.45
AUDI	5000S	87	46.04	46.04	117.48	66.68	101.60	76.20	17.46	33.34
HONDA	ACCORD LX	85	44.45	53.98	120.65	53.98	130.18	123.83	22.23	91.31
VW	GOLF	87	41.28	41.28	104.78	65.09	80.96	60.33	19.05	41.28
CHRYSLER	LANCER	85	53.98	53.98	111.13	60.33	136.53	136.53	-3.18	76.20
TOYOTA	CRESSIDA	82	44.45	44.45	111.13	63.50	120.65	120.65	4.76	65.09
NISSON	300ZX	85	50.80	50.80	158.75	69.85	114.30	85.73	-.40	-7.54
VOLVO	GL 4 DOOR	83	34.93	47.63	123.83	76.20	123.83	123.83	-3.18	30.16
PONTIAC	6000 STE	86	57.15	69.85	133.35	60.33	146.05	123.83	9.53	122.24
CHEVROLET	CHEVETTE	85	31.75	31.75	69.85	63.50	60.33	44.45	36.51	6.35
RENAULT	ALLIANCE	83	44.45	44.45	111.13	63.50	104.78	104.78	19.05	44.45
CHEVROLET	CAVALIER RS	87	47.63	57.15	127.00	63.50	111.13	95.25	19.05	95.25
CADILLAC	BROUGHAM	87	53.98	76.20	222.25	60.33	146.05	127.00	28.58	33.34
CHEVROLET	CAPRICE CLASSIC	87	57.15	73.03	155.58	60.33	146.05	127.00	-28.58	33.34
CADILLAC	SEVILLE	87	57.15	66.68	130.18	63.50	142.88	127.00	-28.58	127.76
	MAXIMUM		63.50	76.20	222.25	76.20	149.23	142.88	36.51	127.76
	MINIMUM		30.16	30.16	69.85	44.45	60.33	44.45	-28.58	-7.54
	MEAN		48.03	53.05	124.90	61.30	117.01	105.49	6.34	61.79
	STANDARD DEVIATION		7.75	11.40	25.16	6.78	23.87	26.43	17.00	38.45

LEGEND

C1T = ACCEL.L PEDAL WIDTH AT TOP
C1T = ACCEL. PEDAL WIDTH AT BOTTOM
E2 = ACCEL. PEDAL LENGTH
F3 = BRAKE PEDAL LENGTH
X4T = BRAKE PEDAL WIDTHTH AT TOP
X4B = BRAKE PEDAL WIDTH AT BOTTOM
X12 = SEAT CEN. TO ST. WHEEL CEN
A13 = ST. WHEEL CEN. TO RIGHT SIDE OF BRAKE PEDAL



Dimension Codes Described in Table 7-4

FIGURE 7-6. T VALUES FOR 1973-81 ODI DATA COMPARED TO 1978-86 AUDI 5000

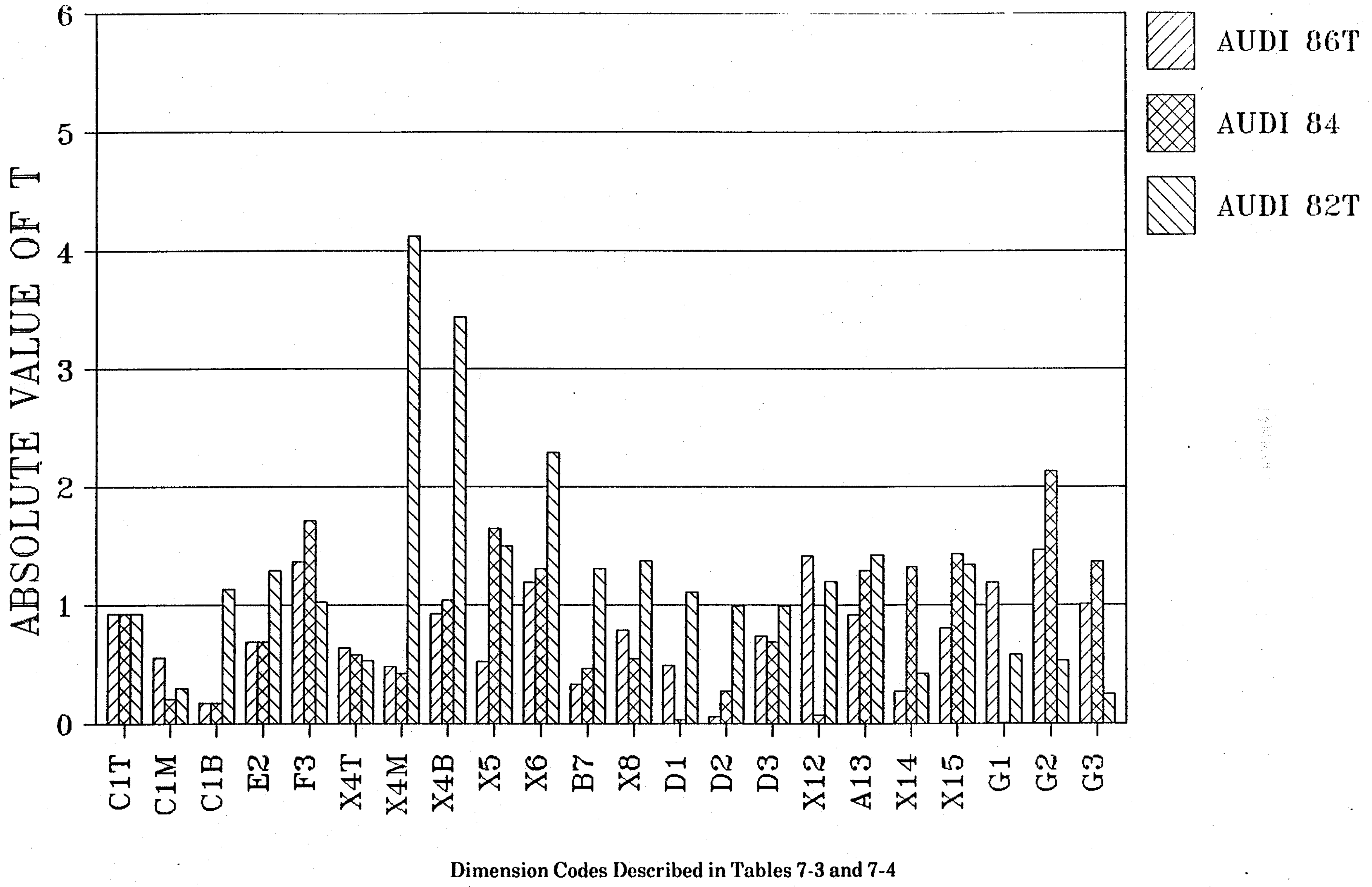


FIGURE 7-7. T VALUES FOR 1982-86 TSC DATA COMPARED TO 1982-86 AUDI 5000

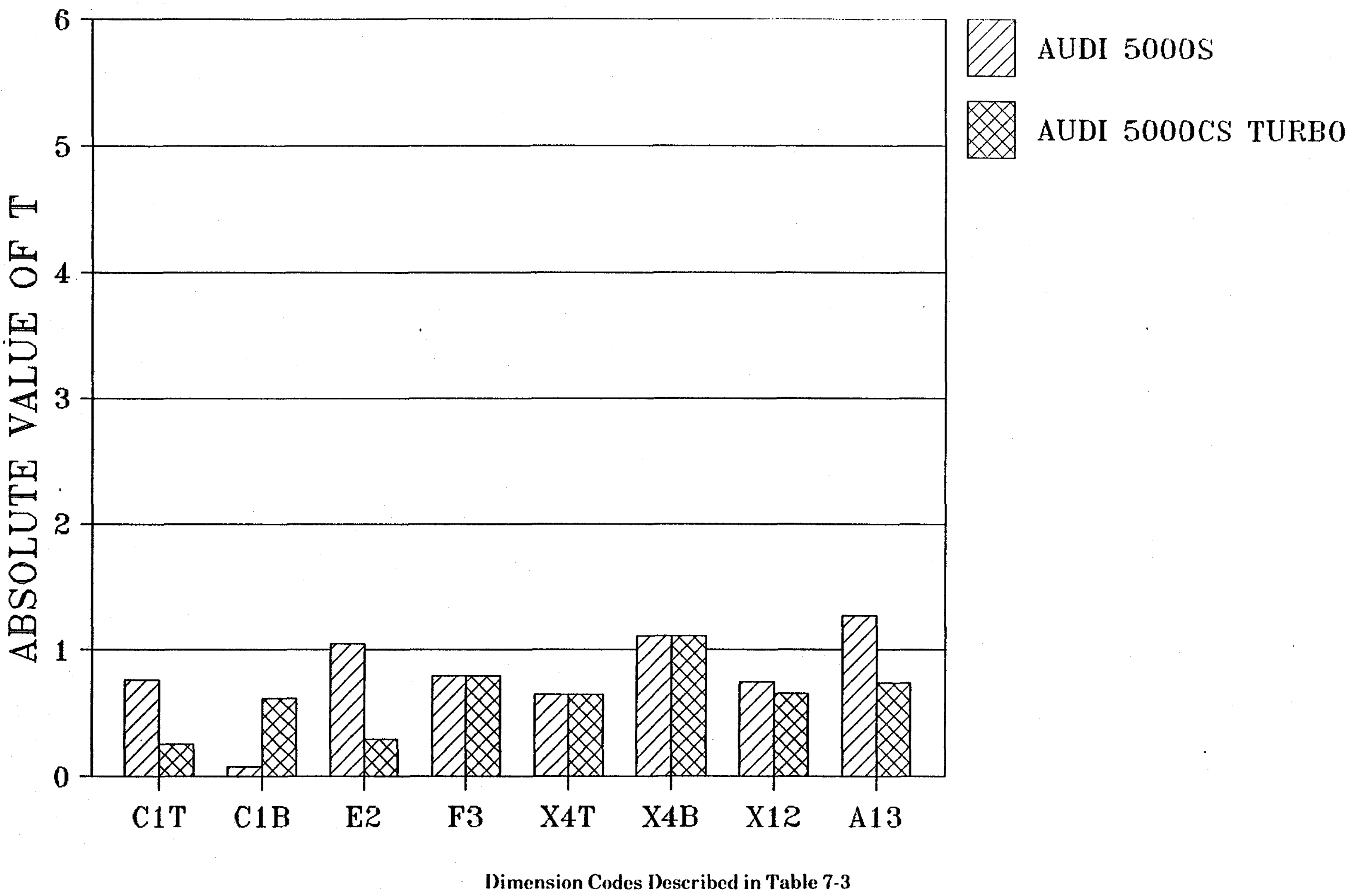


FIGURE 7-8. T VALUES FOR 1982-87 ODI DATA COMPARED TO 1985-86 AUDI 5000

TABLE 7-4. AVERAGE PEDAL DIMENSIONS (mm) COMPARED TO AUDI 5000 AND SELECTED CADILLACS

	ATTRIBUTE MODEL YEAR	NHTSA/ODI		TSC 84-85	AUDI		CADILLAC				
					5000	5000	CIMARRON	COUPE DEVILLE		ELDORADO	
		75-81	83-87		78-83	84-86	83	78	85	79	85
A	Steering Wheel to Right Side of Brake Pedal	28.3	61.7	58.6	15.7	34.0	37.3	32.0	63.5	80.0	76.2
X4T	Brake-Pedal Width	--	111.2	112.8	110.0	88.9	---	---	129.3	---	194.6
B	Horizontal Pedal Separation	71.5	67.8	80.5	60.3	60.2	73.0	63.5	63.0	57.1	---
C	Accelerator-Pedal Width	54.7	50.5	49.0	51.6	53.2	50.0	79.0	52.3	78.0	63.5
D1	Accelerator Pedal to Top Edge Hump	17.2	---	53.0	30.2	57.9	---	18.0	---	66.0	124.0
D2	Accelerator Pedal to BTM Edge Hump	13.4	---	41.8	30.2	36.1	---	12.0	---	58.0	70.0
E	Accelerator-Pedal Length	154.5	125.0	132.5	82.5	103.1	123.9	233.0	137.0	195.0	190.0
F	Brake Pedal-Length	51.6	61.2	58.3	65.0	67.9	47.5	61.0	65.8	67.0	65.0
G1	Vertical Pedal Separation 0 lb	62.3	---	69.3	52.3	48.7	88.1	69.0	86.6	66.0	72.9
G2	Vertical Pedal Separation 20 lb	17.5	---	32.0	29.4	17.5	42.9	41.0	42.9	19.0	50.8
G3	Vertical Pedal Separation 75 lb	-7.6	---	-55.1	-58.6	-47.1	-66.0	21.0	-67.0	-2.0	-72.9
	Total Travel G1-G3	69.9	---	124.4	110.9	95.8	154.1	48.0	153.6	68.0	145.8

Another significant change which has occurred is in the brake-pedal "feel" and travel under identical applied forces. The older (1975 to 1981) "full-size" cars had significantly "harder" power brakes with much less total travel. The mean pedal travel for these vehicles (engine running) with 75 lb. of applied force is 69.9 mm, whereas the total travel for 1984 to 1985 vehicles is 124.4 mm. Again, a comparison of old and new Cadillacs dramatically illustrates this change. The 1978 DeVille's brake pedal only traveled 48.0 mm (less than 2 in) with 75 lb. of force, whereas the 1985 model traveled 153.6 mm. By way of comparison, Audi has increased the hardness of its brakes; the 1978 to 1983 Audi was 110.9 mm at 75 lb., and the 1984 to 1986 Audi had 95.8 mm of travel. (Note: This difference may reflect vehicle-to-vehicle measurement differences and not design differences.)

The Audi's pedal dimensions and locations are, with a few notable exceptions, similar to the vehicles found in the 1984 to 1985 data, both domestic and imported, but significantly different from older domestic vehicles. The exceptions are the distance from the right side of the accelerator and brake pedal to the steering-wheel centerline, which was less than that found in the aggregate, and the shorter length of the accelerator pedal.

In the 1985 Audi, for example, the distance between the steering-wheel centerline and the right side of the brake pedal was 1.25 in, while the mean distance from steering-wheel centerline to the right side of the brake pedal in the 1983 to 1987 ODI data set was 2.43 in (SD = 1.5).

The Audi accelerator pedal is further from the center hump than other vehicles (some front-wheel-drive vehicles have indistinguishable humps). Table 7-5 compares some other Audi pedal dimensions to newer domestic and foreign vehicles. These dimensions are not available for older vehicles. Of interest here are the accelerator and brake-pedal heights. The average accelerator-pedal height for all vehicles in the databases previously referenced is 71.0 mm, whereas the Audi was 139.0 mm in 1983 and 110.0 mm in 1986. Comparable numbers for the brake-pedal heights are 147.3 mm for all vehicles and 168.0 mm and 152.0 mm for the Audis, respectively. These results indicate that the Audi accelerator pedal is significantly higher than that of other vehicles, whereas the brake pedal is similar in height.

There are no automotive industry standards for pedal arrangements and forces. However, the dimensions and forces recommended for use in military systems (Vancott et.al.) are given in Table 7.5. Comparisons of these dimesions with those of Audi and the U.S. fleet again indicate that the Audi brake pedal, though somewhat smaller than optimum, is not significantly different from the overall fleet average. The accelerator pedal, however, is significantly shorter and higher than both the optimum and the overall fleet average.

In summary, the Audi driving compartment is different from that encountered in older foreign and domestic vehicles and, to a lesser degree, newer domestic vehicles. On the average, only 6 Audi seating attributes out of 22 were within 1 standard deviation of the mean for all GM vehicles from 1975 to 1983. The Audi seat is higher and harder than the equivalent domestic vehicle, and the floor covering is thicker. In adjusting the Audi seat to accommodate a small driver, the knee angle and seat depth are less than optimum and may contribute to a compromised driving position. The centerline of the Audi seat is displaced to the left of the centerline of the steering wheel by less than 20 mm, although some drivers complained about the misalignment of the steering wheel. Subjects representing 5th percentile females and 50th and 95th percentile males were tested in the vehicle and found the eight-way power seat to be very accommodating. The only complaint was the lack of leg room for the tall male.

TABLE 7-5. FLOOR PEDAL DIMENSIONS

	Recommended	Avg. All	Audi 78-83	Audi 84-86
BRAKE				
Width	102 mm	112.0	100.0	88.9
Length	76 mm	57.0	65.0	67.9
Height	203 mm	147.3	168.0	152.0
Force in Normal Operation	4 to 30 lb/ft	---	---	---
Normal Travel	50 to 150 mm	97.1	111.0	96.0
ACCELERATOR				
Width	89 mm	51.4	51.6	53.2
Length	250 mm	137.3	82.5	103.1
Height	76 mm	71.0	139.0	110.0
Force	6 to 9 lb/ft	---	---	---
Normal Travel	20°	---	---	---
HORIZONTAL PEDAL SEPARATION	76 mm	70.0	80.5	60.3

Recent research, funded by Audi and conducted by Rogers and Wierwille (1988), indicated that differences in pedal configurations can be associated with large differences in pedal-use errors. In this study, only the frequency of relatively minor errors had a statistically significant relation to pedal configuration. (The frequency of serious errors observed during the course of the study was too low to be tested conclusively.)

The pedal dimesions and forces may be of particular interest because the basic clues a driver uses to determine which pedal he or she is depressing are:

- the absolute and relative height of the brake and accelerator pedals
- the force deflection characteristics of the pedals
- the lateral location of the accelerator and brake pedals relative to each other and to landmarks such as the steering-wheel centerline and the center hump.

In the 1978 to 1983 and 1984 to 1986 Audi 5000, a number of these dimensions are outside the range of those found in the U.S. vehicle fleet for the periods when the Audi vehicle was marketed. It can be speculated that the nonconformity of the Audi dimensions to other vehicles in the U.S. fleet contributes to the likelihood of pedal misapplication.

A comparison of the Audi dimensions and forces to the U.S. data lends support to the hypothesis that a driver who is familiar with an older domestic vehicle may find the Audi seating and pedal arrangement to be different, thereby increasing the likelihood of stepping on the throttle pedal rather than the brake in a panic situation.

7.3 DRIVER FACTORS

In this section, the characteristics of drivers involved in SAIs and the driving conditions under which SAIs occur are discussed.

One possible reason that Audi 5000s are overrepresented with regard to SAIs is that Audi drivers may have been drawn from a population of drivers having more of these types of accidents. The likelihood of an individual being involved in an accident may be statistically related to factors such as the driver's age, sex, and height; the familiarity of the driver with the vehicle; and the frequency of exposure of the vehicle to situations wherein such accidents are likely to occur. To better understand the influence of factors such as driver characteristics and situational exposure, TSC compared the Audi incidents to accidents found in the NASS and CARDfile traffic accident databases.

Accident databases where chosen because of the lack of traffic-related incident databases. Incidents and accidents are both unintended phenomena, and although the Audi SAIs did not always result in an accident, the potential similarities in causation make the comparisons that follow valuable in understanding the problem.

Audi driver characteristics such as age, sex, and height are considered for a number of reasons. (See Section 7.3.2 for a detailed discussion of driver height.) It is known that driver age relates to accident rate. Numerous studies have indicated that both the youngest and oldest drivers are over-involved in accidents. In terms of frequency, males are responsible for far more than half of the total accidents. However, in terms of exposure (i.e., accidents per vehicle mile of travel as implied by NPTS data), the rate for men and women is approximately the same. This is because men drive twice as many miles as women. Exposure is, of course, a much more complex factor than miles driven. It involves considerations such as traffic density, weather conditions, time of day, and trip length. All of these factors relate to the economic situation of the buyer or driver and the use to which the vehicle is subjected. Finally, driver height is of value in relating driver-size characteristics to the interior compartment and pedal measurements that were discussed in the previous section.

7.3.1 Age and Sex

Table 7-6 gives the age and sex distribution of drivers involved in Audi SAIs and compares them to all drivers involved in Audi accidents in the state of Texas in 1984 (from CARDfile) and drivers involved in all accidents in 1984 (from both NASS and CARDfile). (Note that the Texas accidents may include sudden acceleration-caused accidents.) NASS and CARDfile both show that young male and female drivers are overrepresented in accidents. However, males are involved in twice as many accidents as females. Male drivers under 30 are involved in approximately 30 percent of the accidents. Females follow these same trends, but at one-half the rate. The incidence of accidents then decreases in middle age and increases slightly with old age. In total, males account for more than 60 percent of the accidents.

When 704 Audi accidents in the state of Texas were examined, a somewhat different picture appears; male drivers under 30 were found to be involved in about 20 percent of all accidents and females under 30 in about 18 percent of the accidents. The middle ages (30 to 50) show an increase in both male and female accident involvement, accounting for approximately 25 percent each. Males were responsible for 53.0 percent and females for 48.8 percent of the Texas Audi accidents. These trends are more evident in the SAI figures. Male and female drivers under 30 years of age account for only 3.6 and 5.3 percent of the incidents reported to ODI. Middle-aged drivers (30 to 49 years of age) were involved in 15.5 and 27.8 percent of the incidents (males and females, respectively). Older (over 50) drivers, both male and female, are also overrepresented relative to all accidents at 20.8 and 24.3 percent. In total, male drivers reported 39.9 percent of the SAIs and females 57.4 percent, almost the opposite of overall accident patterns.

Assuming female drivers are not inherently less safe drivers (they are not more likely to be involved in traffic accidents in general than males), factors other than driver skill are likely to contribute to female over-involvement in the Audi SAIs. These factors include the age and sex of the Audi 5000 buyer and driver population as compared to the general population, the type of driving done in the Audi (exposure of the driver and vehicle) as a function of age and sex, and the drive cycle of the vehicle (trip length and frequency).

According to Audi, the average Audi buyer is a middle-aged male in an upper economic bracket. This suggests that the age of the driver in Audi accidents and SAIs should be higher than for all drivers' accidents. In order to test this hypothesis, the Audi accidents were compared to those of the Cadillac Coupe DeVille in Texas using 1984 CARDfile data (Table 7-7). This comparison assumes that the buyers of Audis and Cadillacs are from similar economic and age brackets.

Approximately the same sex distribution was found in the Cadillac and Audi accidents in Texas, with males slightly outnumbering females. Both vehicle models are somewhat underrepresented in young driver accidents when compared to NASS.

Audi accidents are highest in the 20 to 40 age bracket (for both males and females), whereas the Cadillac is higher in the over 60 age bracket, perhaps reflecting a slightly older driver of the Cadillac. These results indicate that accident age and sex distribution is influenced by the economic situation of the buyer or driver and that either females from better economic circumstances are more frequently involved in accidents (an unlikely hypothesis) or that, proportionately, women are more likely to drive these types of vehicles. Although these economic factors partly explain the over-involvement of middle-aged and older women in SAIs, it would appear that other factors are also at work.

TABLE 7-6 AGE AND SEX OF INCIDENT - AND ACCIDENT-INVOLVED DRIVERS

Age Years	Audi SA* %		Audi All %		NASS*** %		CARDfile %	
	M	F	M	F	M	F	M	F
<20	0.3	0.3	4.7	3.9	9.3	4.8	9.1	4.7
20-24	1.3	1.0	16.0	14.4	12.3	6.0	12.4	6.0
25-29	2.0	4.0			8.8	4.8	9.9	5.0
30-34	2.0	4.0	17.0	19.6	6.2	4.0	7.4	4.1
35-39	4.6	8.6			5.6	3.4	5.6	3.3
40-44	3.6	8.6	8.2	6.3	3.7	2.4	4.0	2.3
45-49	5.3	6.6			3.0	1.6	3.0	1.6
50-54	4.0	9.2	5.0	3.3	2.4	1.1	2.7	1.4
55-59	5.6	5.6			2.5	1.5	2.6	1.3
60-64	6.6	3.6			2.5	1.6	2.7	1.1
65-69	2.6	3.3	2.1	1.3	1.8	0.6	1.5	0.8
>69	2.0	2.6			3.0	1.5	2.4	1.4
Total	39.9	57.4	53.0	48.8	61.1	33.3	63.3	33.0

* SA - Sudden acceleration
** Assumes unknowns are distributed the same as knowns
*** Excludes those where sex is unknown

TABLE 7-7. COMPARISON OF AUDI AND CADILLAC INCIDENTS

Age Years	Audi SA* %		Audi All %		Cadillac %		NASS** %	
	M	F	M	F	M	F	M	F
<20	0.3	0.3	4.7	3.9	3.4	1.9	9.3	4.8
20-29	3.3	5.0	16.0	14.4	9.5	5.7	21.1	10.8
30-39	6.6	12.6	17.0	19.6	9.3	9.3	11.8	7.4
40-49	8.9	15.2	8.2	6.3	9.0	9.7	6.7	4.0
50-59	9.6	14.8	5.0	3.3	9.2	8.6	4.9	2.6
>59	11.2	9.5	2.1	1.3	13.4	10.7	7.3	3.7
Total	39.9	57.4	53.0	48.8	53.8	45.9	61.1	33.3

* SA - Sudden acceleration

** Excludes those where sex is unknown

One other factor to consider is exposure, based on vehicle miles traveled and drive cycle. Vehicle miles traveled, in turn, are also related to driver age, sex, and income. Previous studies have shown a slight but consistent overrepresentation of middle-aged females based upon accidents per miles traveled (Figure 7-9). Males and females are comparable on this basis, which is explained by the difference by sex of vehicle miles traveled.

The 1983-84 NPTS indicated that the average annual miles driven by males was 13,962 and by females 6,382. These mileage figures are also associated with income. The NPTS shows that the average annual mileage for households with more than $40,000 income (average Audi/Cadillac owner) was 11,706 miles, as opposed to the overall average of 10,288 miles (no sex distribution was available). The NPTS also indicates that 87 percent of households with an income of $40,000 or more, which would include the average Audi/Cadillac owner, own two or more vehicles (average = 2.6 vehicles). The drivers in these households are therefore probably exposed to two or more different vehicles.

The type of driving could also be a factor in the apparent over-involvement of females in the Audi SAIs.

Approximately 70 percent of the vehicle trips and 65 percent of the vehicle miles of travel are related to family business and social and recreational affairs. Tables 7-8 and 7-9 from the NPTS show that females make slightly less work-related trips and more family-related trips. In fact, more than 80 percent of female driving is not work-related, while about 70 percent of the males' trips are not related to work. This non-work- related 80 percent includes family and personal business, including shopping and doctor visits. For women, these types of trips increase from 26.2 percent at ages 16 to 19 to more than 45 percent in middle and older ages. (Males also increase this type of travel, from about 20 percent to more than 30 percent.) This type of driving exposes an individual to frequent starts and stops in which the sudden accelerations are more likely to occur.

In summary, middle-aged female drivers and, to a lesser degree, middle-aged male drivers appear to be overrepresented in Audi SAIs. Part of this overrepresentation can be explained by the economic circumstances of those who buy and drive the car. Income is related to age and can also influence the miles driven per year and the number of vehicles in the family, thus increasing the exposure and decreasing the familiarity with a specific vehicle. As income increases, a larger part of the annual mileage is for family and personal business. Middle-aged women and, to a lesser degree, middle-aged men are overrepresented in these travel categories. Frequent short trips such as shopping, social visits, and doctor visits would increase the exposure of the driver to the start-and-stop driving during which SAIs are most frequently reported.

7.3.2 Height

TSC also examined the heights of the drivers in the NHTSA sudden acceleration reports to determine if incident-involved drivers had any physical characteristics that, in conjunction with the vehicle driver compartment design, could contribute to sudden accelerations. Table 7-10 gives the means, standard deviations, and percentiles (assuming a normal distribution) of the male and female incident-involved drivers, and compares them to the national population. Although the means are approximately the same, the Audi-involved drivers are more broadly distributed, i.e., these populations have a greater proportion of shorter and taller drivers than the general population. An "F" test indicates that the Audi distributions are significantly different from the national population. Figures 7-10 and 7-11 show a normal probability plot of these distributions. Although these plots and the "skewness" show some lack of normality in the distributions, this is not enough to affect the results given in the table. As far as the short and tall drivers are concerned, as noted above, the Audi seat may have some difficulty in accommodating a short person, and the compartment may not offer

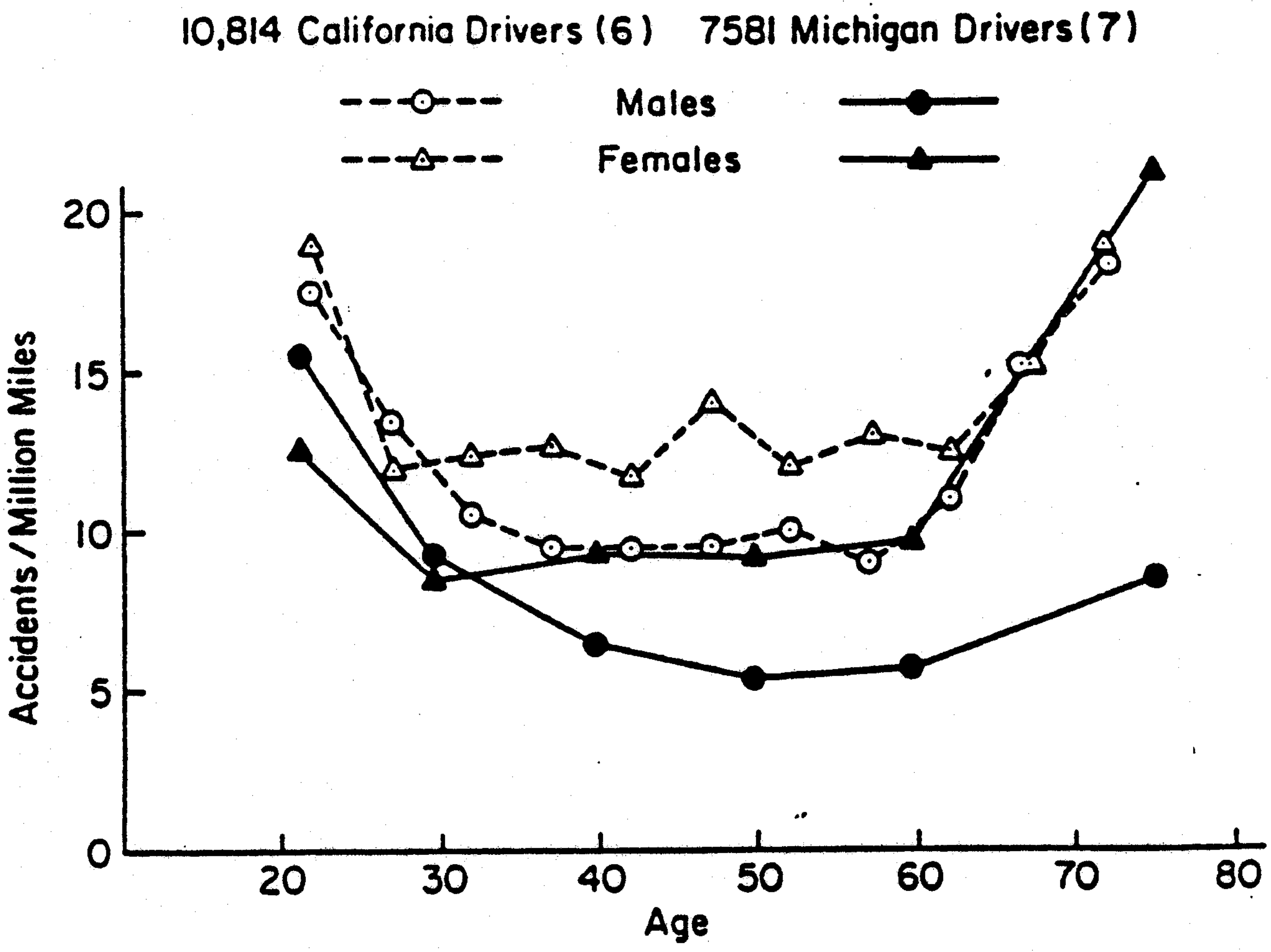


FIGURE 7-9. ACCIDENT RATE AS A FUNCTION OF AGE AND SEX

TABLE 7-8. DISTRIBUTION OF PERSON TRIPS BY PURPOSE, AGE, AND SEX (1983 MALES)

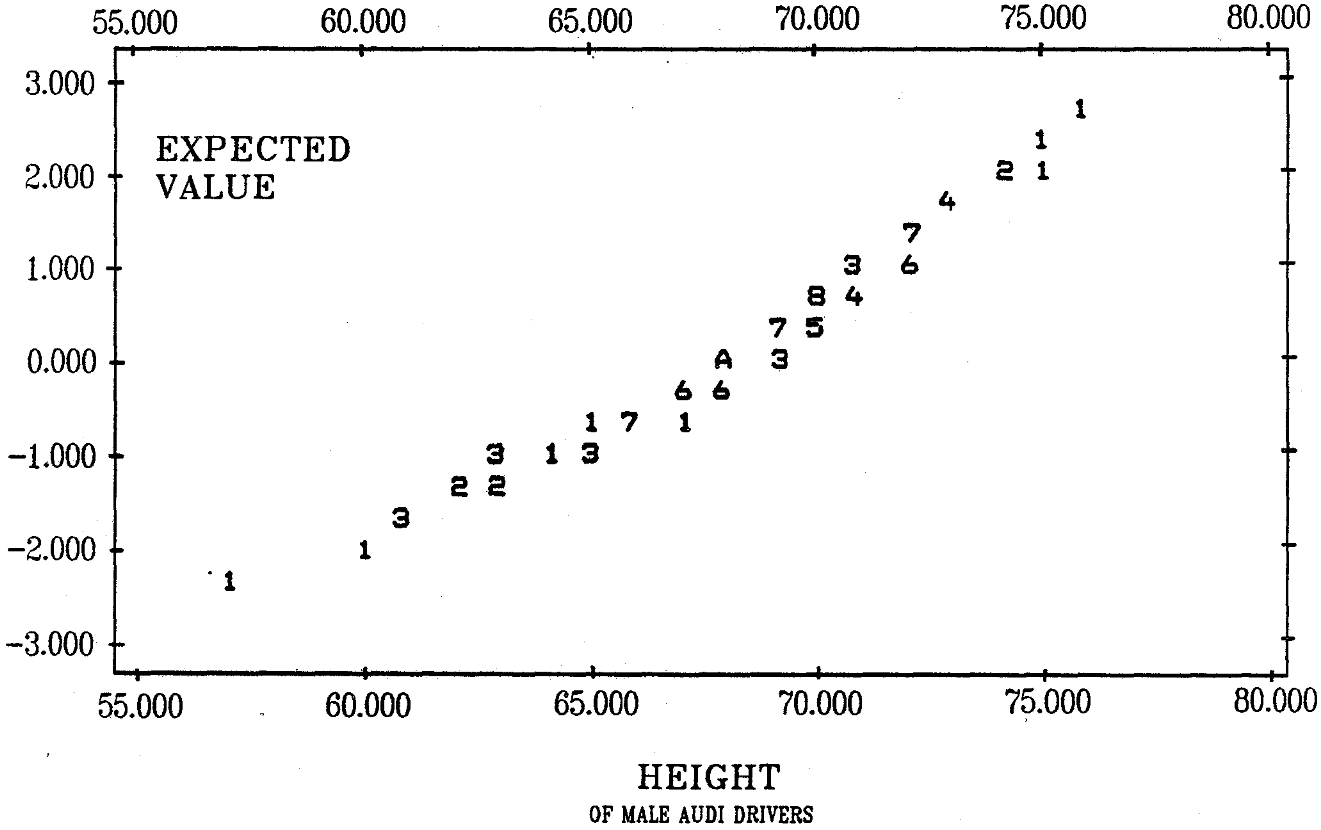
	Age								
	5-15	16-19	20-29	30-39	40-49	50-59	60-64	65 and Over	All
Earning a Living									
To or From Work	1.5	16.2	31.6	33.1	33.9	31.6	26.2	6.7	24.5
Work Related Business	.4	1.6	2.5	4.7	4.4	5.6	3.2	2.1	3.1
Subtotal	1.9	17.8	34.1	37.8	38.3	37.2	29.4	8.8	27.6
Family and Personal Business									
Shopping	9.4	9.4	14.6	16.2	16.4	18.3	19.9	31.2	15.7
Doctor/Dentist	.9	.5	.6	.7	.5	.7	1.7	2.6	.9
Other Family Business	9.0	10.1	14.3	16.7	18.4	16.5	19.2	19.1	15.0
Subtotal	19.3	20.0	29.5	33.6	35.3	35.5	40.8	52.9	31.6
Civic, Educational, and Religious	39.1	24.4	5.6	3.6	3.0	4.4	4.0	5.8	11.1
Social and Recreational									
Vacation	.5	.1	.2	.3	.3	.3	.3	.0	.3
Visiting Friends	11.9	15.8	13.2	9.4	6.1	7.3	10.1	10.3	10.6
Pleasure Driving	.3	.7	.5	.4	.4	.8	.5	1.3	.6
Other Social and Recreational	20.5	19.6	15.5	13.9	15.4	12.5	14.0	18.2	16.0
Subtotal	33.2	36.2	29.4	24.0	22.2	20.9	24.9	29.8	27.5
Other	6.5	1.6	1.4	1.0	1.2	2.0	.9	2.7	2.2
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 7-9. DISTRIBUTION OF PERSON TRIPS BY PURPOSE, AGE, AND SEX (1983 FEMALES)

	Age								
	5-15	16-19	20-29	30-39	40-49	50-59	60-64	65 and Over	All
Earning a Living									
To or From Work	1.2	10.0	21.2	20.8	22.6	22.2	16.4	6.0	16.5
Work Related Business	.5	.6	2.0	2.1	2.1	2.7	.8	.9	1.7
Subtotal	1.7	10.6	23.2	22.9	24.7	24.9	17.2	6.9	18.2
Family and Personal Business									
Shopping	11.2	15.4	18.8	20.4	23.2	25.4	28.8	30.1	20.3
Doctor/Dentist	1.3	.6	1.0	1.6	2.0	1.6	1.6	4.5	1.6
Other Family Business	10.6	10.2	16.8	23.7	20.0	15.1	17.5	17.1	17.2
Subtotal	23.1	26.2	36.6	45.7	45.2	42.1	47.9	51.7	39.1
Civic, Educational, and Religious	36.6	25.1	8.1	6.1	5.5	7.6	6.0	9.2	12.5
Social and Recreational									
Vacation	.3	.2	.3	.4	.3	.4	.4	.3	.3
Visiting Friends	12.5	15.7	14.4	8.7	9.0	9.6	10.8	10.6	11.4
Pleasure Driving	.7	.5	.2	.4	.6	.6	.2	1.3	.5
Other Social and Recreational	18.1	19.9	15.9	14.0	12.9	13.4	15.5	17.3	15.6
Subtotal	31.6	36.3	30.8	23.5	22.8	24.0	26.9	29.5	27.8
Other	7.0	1.8	1.3	1.8	1.8	1.4	2.0	2.7	2.4
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 7-10. DISTRIBUTION OF HEIGHTS FOR MALE AND FEMALE DRIVERS INVOLVED IN SUDDEN ACCELERATION INCIDENTS AS COMPARED TO THE NATIONAL POPULATION

	Male (in)		Female (in)	
Percentile	U.S.	Audi	U.S.	Audi
1	62.6	60.2	57.8	56.5
2.5	63.6	61.5	58.7	57.8
5	64.4	62.6	59.5	58.8
25	67.0	66.1	61.9	62.1
50	68.8	68.5	63.6	64.4
75	70.6	70.9	65.3	66.7
95	73.2	74.4	67.7	70.0
97.5	74.0	75.5	68.5	71.0
99	75.0	76.8	69.4	72.0
n =	>10,000	99	10,000	158
Q	2.67	3.57	2.50	3.41
MAX		76		76
MIN		57		52



In Figures 7-10 and 7-11, the observed values are plotted along the horizontal axis. The data values are ordered before plotting. The vertical axis corresponds to the expected normal value based on the rank (quartile) of the observation. The plotted points represent the set of points (x(i), q(i)) where the x(i) are actual observations after ordering (i.e., x(1) is the point with the least magnitude and x(n) is the largest value) and q(i) is the standard normal with probability level (i-1/2)/n. When the points lie very nearly along a straight line, the normality assumption remains tenable.

FIGURE 7-10. NORMAL PROBABILITY PLOT OF MALE AUDI DRIVERS

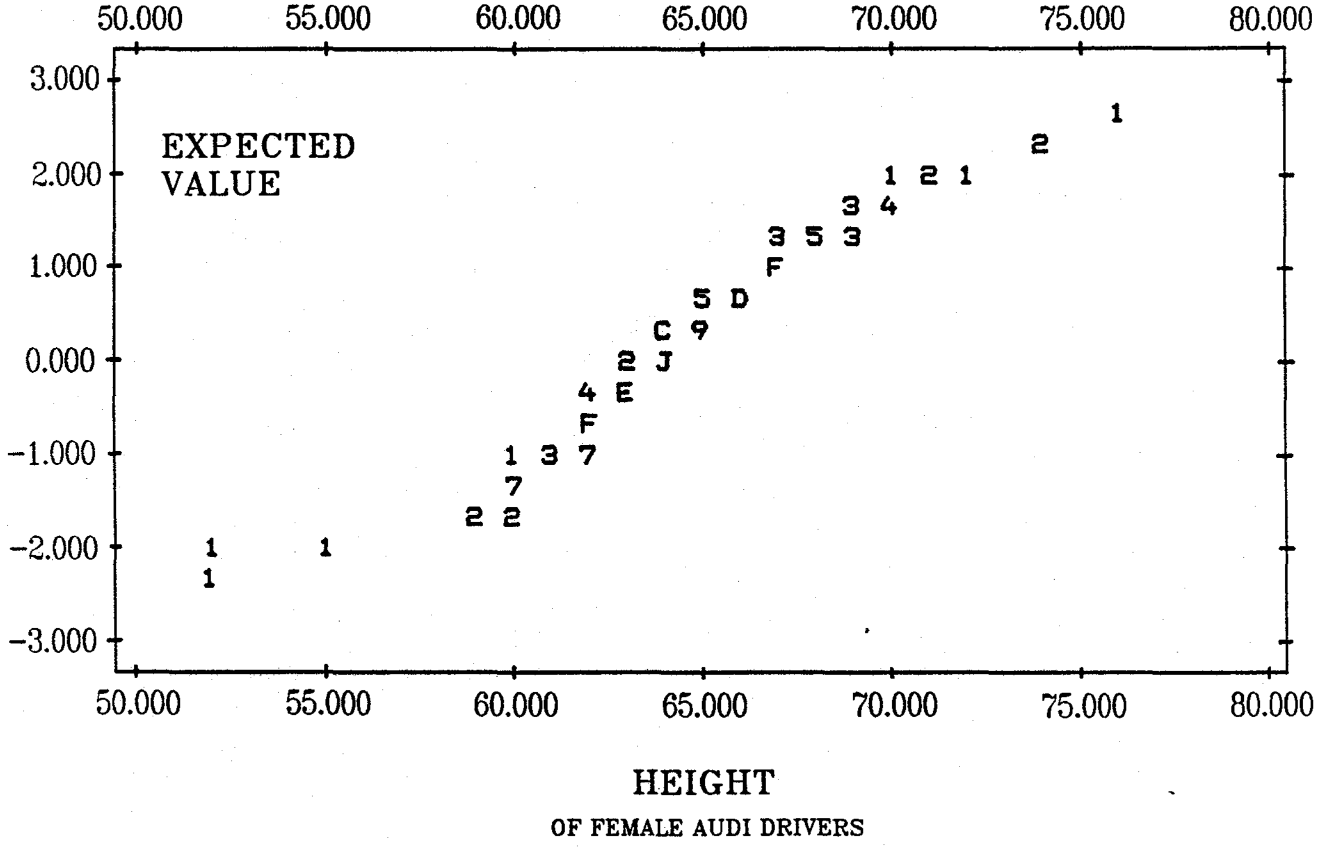


FIGURE 7-11. NORMAL PROBABILITY PLOT OF FEMALE AUDI DRIVERS

enough leg room for a tall person. This data cannot prove height is a causative factor, however, because it is possible that Audi buyers and drivers are taller or shorter than the normal population.

7.3.3 Experience

This section examines experience from two points of view which may be considered a manifestation of the same phenomenon:

- The driver's experience with the vehicle.
- The mileage the vehicle was driven at the time of the accident or incident. (This factor is an indicator of driver inexperience, but may also be indicative of a vehicle component failure that is mileage-or time-related.)

A study performed by NHTSA in 1983 reviewed the accident literature with respect to driver familiarity with the involved vehicle and overall driver experience. Figure 7-12 is taken from that study and indicates that driver experience with the accident vehicle is more closely related to accident rate than overall driving experience. (In fact, 17 to 24 percent of all drivers involved in accidents have less than 1000 miles of experience with the involved vehicle.)

This problem may be more pronounced for Audi SAIs. According to Audi, the majority of the interviewed drivers involved in SAIs did not own the vehicle or did not drive it regularly. The experience of drivers involved in Audi incidents as reported to NHTSA is also plotted in Figure 7-12. These data show that 44 percent of the Audi SAI-involved drivers had less than 6 months of experience with the vehicle. This is substantially greater than the percentage of all accidents experienced by drivers (34 percent in the first 6 months), and may indicate that (1) unfamiliarity with the vehicle is a greater causal factor in sudden acceleration, or (2) the vehicle is new and there is a component problem that manifests itself early in the car's life so that the incident occurs when the owners have had the car for only a short time.

Another way of examining this effect is to consider the odometer mileage at the time of the accident or incident. Figure 7-13 shows the odometer mileage for Audi incidents as reported to both Audi and NHTSA. The Audi figures show that about 70 percent of the SAIs occurred with less than 10,000 miles on the odometer, while the NHTSA data show that 45 percent of the SAIs occurred with less than 10,000 miles driven. Figure 7-14 illustrates the 1984 weighted national accident experience for all vehicles and for Cadillacs, drawn from NASS odometer readings. The overall accident experience is evenly distributed between 3.5 and 4 percent per 5,000 miles of odometer reading.

There remains the hypothesis that the overrepresentation of low mileage incidents is a function of "juvenile" component failure. However, the data do not support this theory. Component failures are contributing factors in only 1 percent of the NASS accidents, and of the 704 Audi accidents in Texas, none were attributed to component failures.

In summary, the data suggest that experience of the driver with a vehicle is a factor in the causation of accidents. This experience factor is strongly represented in the data from the Audi incidents. The Audi incident experience is heavily biased to the low mileages while the general accident experience is more evenly distributed as a function of vehicle mileage.

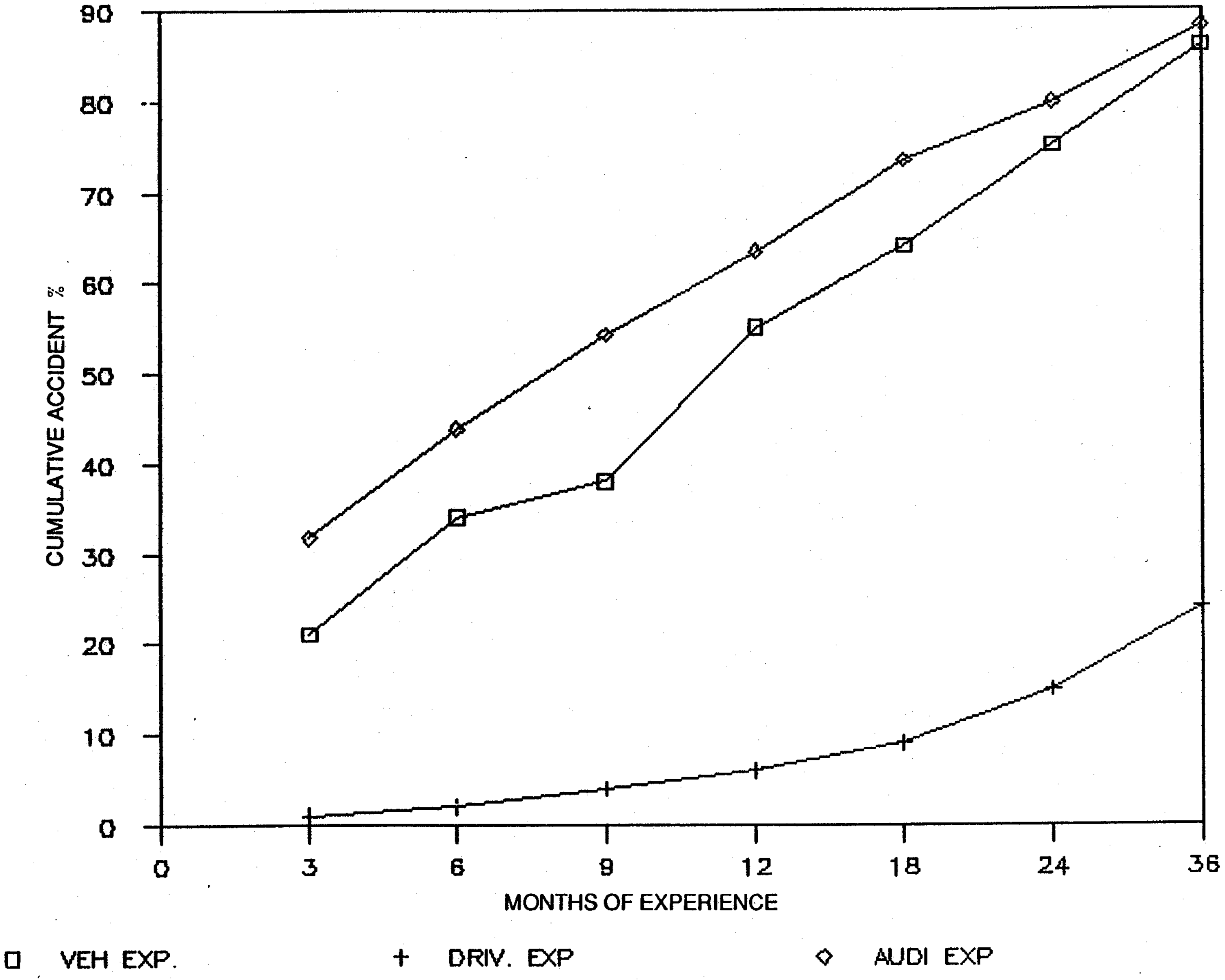


FIGURE 7-12. CUMULATIVE ACCIDENT PERCENTAGE AS IT RELATES TO DRIVER EXPERTISE

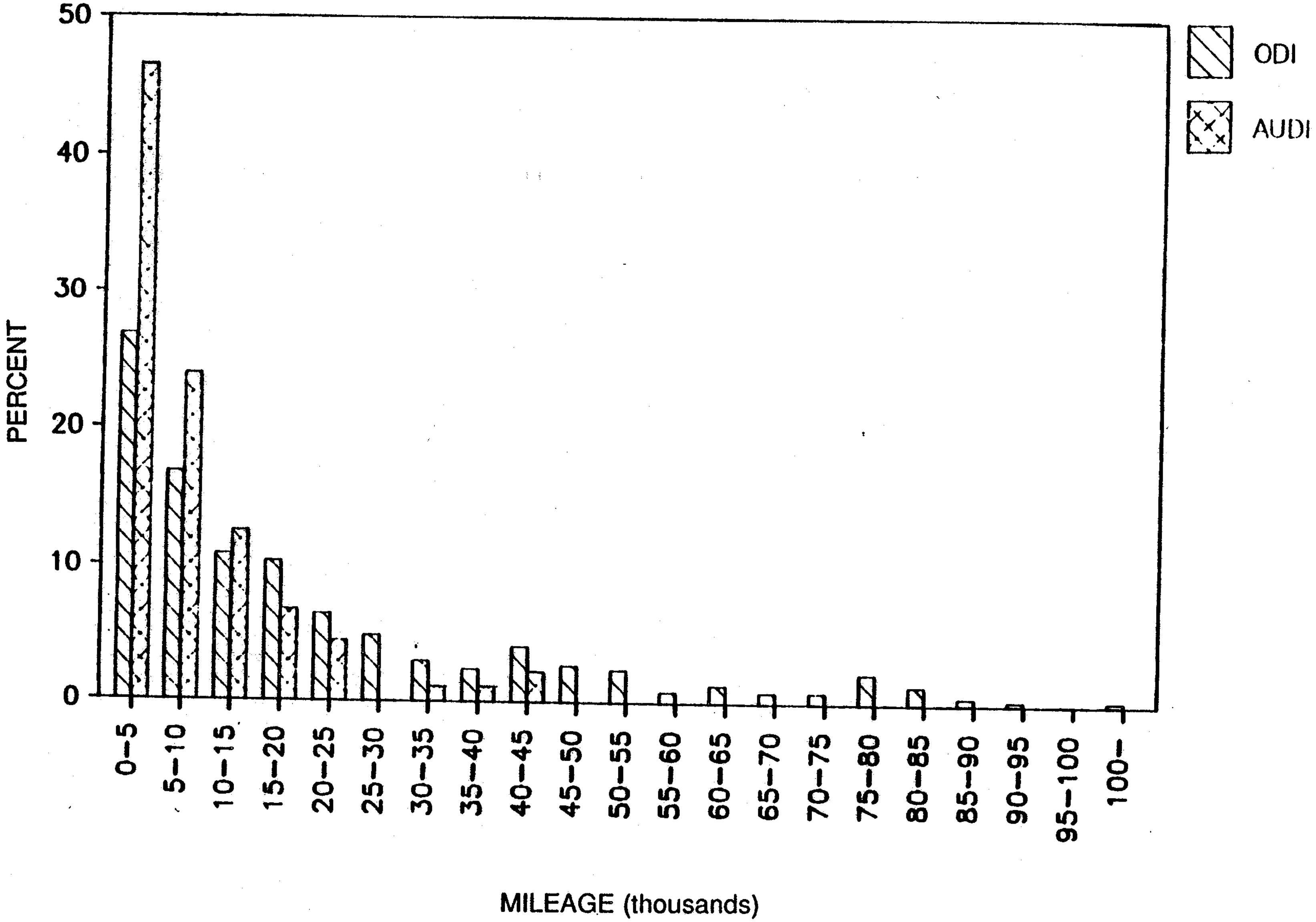


FIGURE 7-13. AUDI INCIDENTS AS A FUNCTION OF MILEAGE

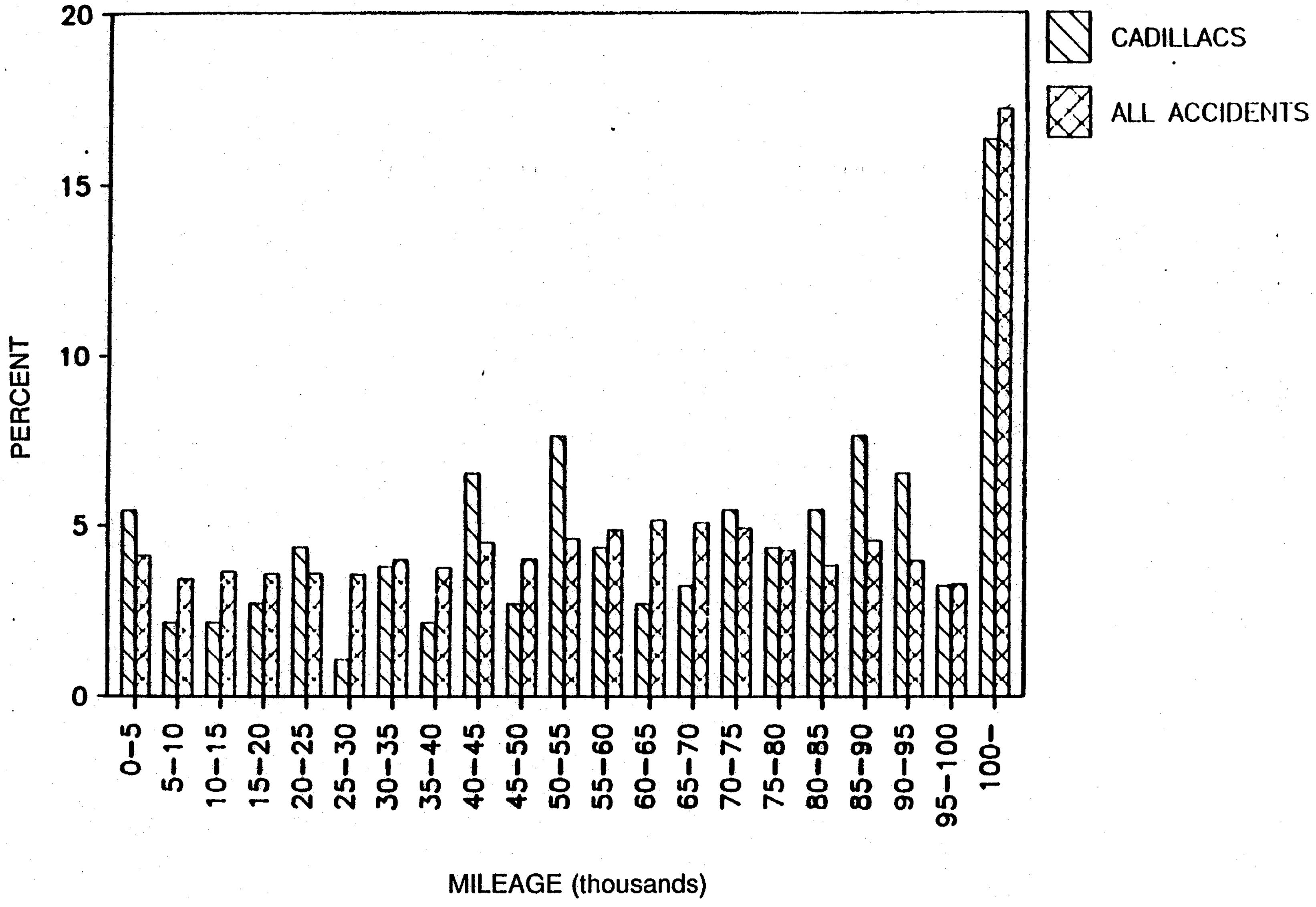


FIGURE 7-14. ACCIDENTS AS A FUNCTION OF MILEAGE

8. RECOMMENDATIONS AND CONCLUSIONS

8.1 POWER TRAIN

The mechanical systems in the Audi that could produce the increase in engine power required to initiate an SAI either directly or by startling the driver are limited. They include the throttle system (the accelerator linkage, transmission "feedback" linkage to the accelerator linkage, and the cruise control) and the idle-stabilizer system (electronic control unit and valve).

8.1.1 Throttle Control System

A failure in this system can directly increase engine power.

Cruise Control System – Multiple failures in this system would be required to produce SAIs under the conditions reported by the involved drivers. Unanticipated acceleration has been observed by TSC and reported to NHTSA and VWOA. However, these acceleration incidents do not resemble the typical SAI in that they have only been observed at highway speeds with the transmission in drive.

Sticking or Binding of Throttle Linkage – After the accelerator pedal is depressed the linkage could "stick," causing the pedal to hold its position. This could be caused by binding in the system or some mechanical interference with the linkage or pedal. Evidence of such sticking or binding should be observed in post-accident investigations. Subsequent to VWOA's recall to modify the accelerator pedal to prevent interference with the floormat, there have been no observed incidents of throttle system sticking.

Transmission Activation of Throttle – In the Audi 5000 from 1978 through 1983, the transmission could activate the linkage and throttle plate in a shift from drive into neutral, reverse, or park. In these models the throttle plate could also be inadvertently opened if the kickdown valve was driven into the transmission by at least 117 psi of pressure. A pressure leak from the transmission main channel is the only source of this high pressure. An SAI due to transmission activation of the throttle would require the failure of one or more valves, would be irreversible, and would be easily detected in post-accident investigations. Such an occurrence has not been observed.

8.1.2 Idle-Stabilizer System

A failure in this system in the Audi 5000 can induce engine surging and unanticipated acceleration. Tests by both VWOA and TSC have indicated that the idle-stabilizer system alone can accelerate the Audi 5000 at 0.3 g reaching speeds of 20 to 25 mph in approximately 10 seconds, eventually reaching speeds of 40 to 50 mph in drive.

Idle-Stabilizer Valve – Two valve configurations have been used by Audi since 1984: a linear valve and a rotationally activated valve. TSC examined three failure modes (mechanical sticking, a "dead spot" on the current collector, and a broken return spring). Only spring failure would cause the valve to stay in the fully open position. Audi has recognized stabilizer valve problems and is examining the valve as part of their recall campaign.

Idle-Stabilizer Electronic Control Unit – Intermittent malfunctions of this unit have been observed and recorded by TSC and others. When this unit malfunctions, excess current flows to the idle-stabilizer valve causing it to open fully, resulting in an immediate increase in engine power. Control unit failures are sometimes temperature-dependent and, because of their intermittent nature, may not be detected during normal Audi-specified testing or in post-accident investigations. The electronic control unit has been repeatedly modified by VWOA. Audi has recalled the earliest three of the five known versions of this unit. This recall has apparently eliminated the problem.

8.2 BRAKING SYSTEM

Potential failure modes in the Audi 5000's braking system which might cause the driver to lose control after the initiation of an SAI were investigated. The typical description of an SAI by the vehicle driver includes a report of often total brake failure.

8.2.1 Complete Brake Failure

This can be caused only by a loss of hydraulic fluid from the master cylinders or brake lines and wheel cylinders or internal leaks in the master cylinder. (All vehicles of the types reporting SAIs have dual hydraulic systems that minimize the chances of losing both front and rear brakes simultaneously.) Such complete failure is irreversible and would be easily detected after an incident. This has not been the case.

8.2.2 Temporary Failure of the Hydraulic Power-Brake Assist

The hydraulic power boost is independent of other engine functions. If the engine is shut down, the reservoir holds sufficient fluid for 15 to 20 brake operations. The reservoir can be depleted by extended engine shutdown. In theory, with the engine at idle, the reservoir could also be depleted by very rapid pumping of the brakes. No such rapid pumping has been reported in descriptions of the events preceding an SAI. Without the power-brake assist, the brakes are still capable of stopping the car, but require four to five times the force from the driver. Even with failure of the power-boost system, the majority of drivers would still be capable of stopping the car after the initiation of an SAI.

Two points must be emphasized. First, if the Audi engine speed is above 1000 RPM as is usually reported in an SAI, rapid pumping of the brake pedal cannot deplete the reservoir. Second, the Audi brakes, when operating properly at the low road speeds typical of the SAI, will hold or stop the car even under wide-open throttle.

8.3 DRIVER FACTORS

Other factors were identified and analyzed which might be related to a disproportionate number of SAIs for the Audi 5000. They were:

- driver-related design factors which increase the likelihood of pedal misapplication
- driver demographic factors which are related to driver subgroup, accident experience, and exposure of the vehicle to situations where SAIs can occur; and physical characteristics of the populations of individuals who drive the vehicles

VWOA's initial claim was that the SAIs were a result of driver error. The Audi 5000 driving environment and the characteristics of the Audi 5000 driver population were analyzed to determine if such factors could cause or contribute to pedal misapplication resulting in the disproportionate number of SAIs reported for the vehicle.

8.3.1 Driving Environment

Prior research by TSC and NHTSA has revealed that driver unfamiliarity with a vehicle can markedly increase the likelihood of an accident. As part of TSC's efforts, a statistical study was performed comparing the Audi 5000's interior seating and pedal arrangements with hundreds of other vehicle models in the U.S. fleet for critical driver-related dimensions. The study revealed statistically significant differences for dimensions such as seat height; lateral steering-wheel position; leg room; brake-pedal force, size, height, and travel; and accelerator-pedal size and height. In particular, the characteristics of the Audi 5000 were more different than older, larger American models and less different than newer front-wheel-drive cars.

8.3.2 Driver Population

The major sources of statistical variation in automobile accident rates are the demographic characteristics of the driver population. Middle-aged and older drivers are overrepresented in Audi 5000 SAIs when compared to drivers in all accidents nationwide. However, such individuals are similarly overrepresented as owners and drivers of Audi 5000s.

8.3.3 Type of Driving

Female drivers are overrepresented in Audi 5000 SAIs when compared to drivers in all accidents nationwide. NPTS shows that females take more trips which require frequent starts and stops, increasing the opportunity for SAIs.

8.3.4 Experience of the Audi 5000 Driver

Approximately 34 percent of all drivers involved in accidents nationwide have less than 6 months of experience with the vehicle involved. In the case of the Audi 5000 SAIs, 44 percent of the drivers had less than 6 months' experience. According to ODI data, more than 45 percent of the SAIs occurred with less than 10,000 miles on the vehicle. NASS accident statistics show that the overall accident rate is relatively evenly distributed between 3.5 and 4 percent per 5,000 miles of driving. The high initial SAI rate for the Audi 5000 could, of course, be indicative of mechanical failures early in the Audi's life. Such early failures, however, have not been detected.

8.4 SUMMARY

In conclusion, the TSC study found that:

- The Audi 5000 has failure modes that could induce intermittent engine surging and unexpected increases in engine power.
- In particular, failures in the idle-stabilizer system have been observed which produced surges under the conditions described in the SAI reports.
- Complete brake failure, as has been reported in SAIs in the Audi 5000, is a very unlikely event, would be detectable after an SAI, and has not been detected in post-SAI investigations.
- The ergonomic characteristics, seating, pedal arrangements, and pedal forces of the Audi 5000 are significantly different from the standard domestic vehicles (especially older vehicles).

- These arrangements and force differences increase the likelihood of driver confusion of the brake and accelerator pedal (particularly for new drivers and particularly after an unexpected, mechanically caused increase in engine power). Studies revealing the correlation between driver unfamiliarity and a high initial vehicle accident rate are consistent with this supposition.

Since many of the features or components of the Audi 5000's systems mentioned above have been introduced, substantially modified, or eliminated in the course of the model years under investigation, no one failure mode can possibly explain all of the reported incidents. One must conclude therefore, that the history of sudden acceleration problems of the Audi 5000 can only be understood in the context of multiple vehicle malfunctions in combination with the ergonomic characteristics and driver factors discussed above.

As with investigations of this problem in other vehicles, we cannot identify any single malfunction in the Audi 5000 which could simultaneously produce sudden acceleration and brake failure and which would leave no readily observable evidence of its occurrence. Rather, we find that malfunction, in the idle-stabilizer system, and to a lesser extent the throttle linkage and the cruise control, are capable of initiating unintended acceleration. (All known defects of this nature have been subject to recalls). Once such an incident has begun, whether through human mistake or vehicle malfunction, it must be assumed that driver error resulting from panic, confusion, and perhaps unfamiliarity with the Audi often contributes to the severity of the incident, particularly if it lasts more than a few seconds.

8.5 ADDITIONAL RESEARCH

The following additional tests and research were in progress at the time of writing.

1. Experimental determination of the tolerances of various versions of the cruise control for high ambient temperatures and electromagnetic interference from sources such as the air-conditioner clutch and alternator diodes.

2. Empirical studies to determine the relationship between physical factors, such as the dimensions and forces of driver controls and accommodations, and pedal misapplication.

The reader is referred to *An Examination of Sudden Acceleration*, for further discussion of these research topics.

APPENDIX A

IDLE-STABILIZER VALVE

A.1. ELECTROMECHANICAL CHARACTERISTICS

Two idle bypass valves were obtained from Audi. One valve was disassembled to permit a more detailed examination of the internal mechanisms and to measure the stiffness of the torsional spring. (The torsional spring is used to return the valve to its nominal opening when power is turned off.) The second valve was used to measure the electromechanical characteristics of the windings.

The control unit adjusts the airflow by sending electrical signals to the stabilizer valve. The electrical signal consists of two 12 V square waves with different periods. Each square wave is sent to two armature field windings located 90° apart as shown in Figure A-1(a). These square waves are known as duty cycles. A sample of a single 28 percent duty cycle being sent to one armature field winding is shown in Figure A-1(b). The valve opening angle of the idle-stabilization valve is controlled by the equilibrium of the torques acting on the rotor. The three torque-contributing components are the torsional spring, Field Winding I, and Field Winding II. When no voltage is applied, the spring maintains the valve at a position of 10° from the fully closed position. Each field winding exerts a torque dependent on the direction and amount of voltage applied. These measurements provide the torque developed by the spring as a function of valve opening angle. The spring torque equation is:

[A.1]

$$T_s = K_s(\theta - 10) = 0.123(\theta - 10)$$

where T_s = torque of the spring (oz-in)
K_s = spring constant (oz-in/degree)
θ = angle valve displaced from just-closed position (degrees)

The winding torque equations are:

Field Winding I [A.2]

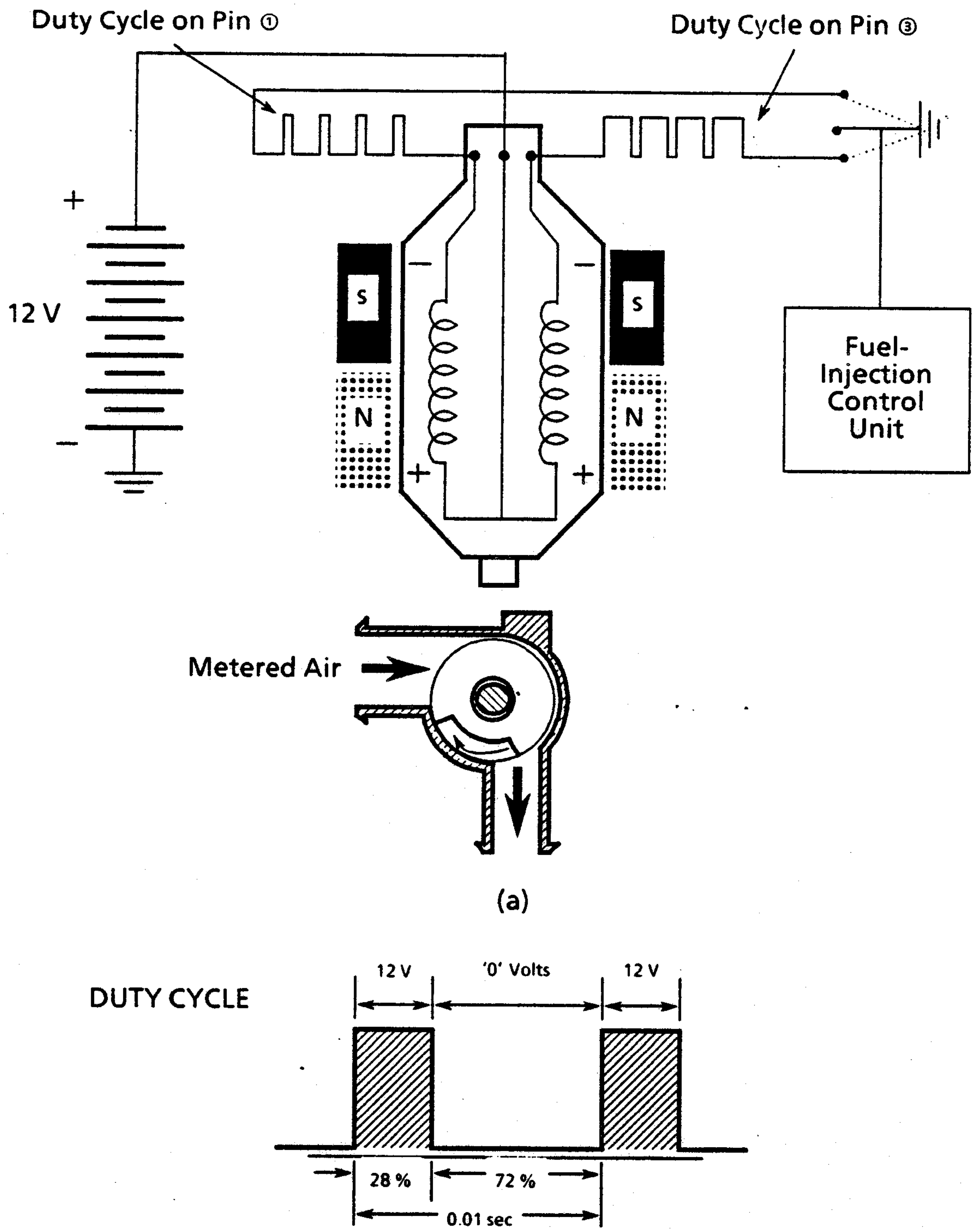
$$T_1 = K_1 V_1 sin(\theta - \theta_1) = (718) V_1 sin(\theta - 159)$$

Field Winding II [A.3]

$$T_2 = K_2 V_2 sin(\theta - \theta_2) = (985) V_2 sin(\theta + 115)$$

where $T_\#$ = torque of field winding (oz-in)
$K_\#$ = winding constant (oz-in/volt)
$V_\#$ = voltage applied (volt)
θ = angle valve displaced (degrees)
$\theta_\#$ = phase angle of winding (degrees relative to closed position)

The continuous curves shown in Figure A-2 show the correlation between the measured data and the characterization above. The symbols represent the measured data points and the lines are the characterizations.



(a)

(b)

SOURCE: CIS-Electronic Fuel Injection Service Training Manual 1986, 21.

FIGURE A-1. IDLE-STABILIZER VALVE SCHEMATIC AND DUTY CYCLE

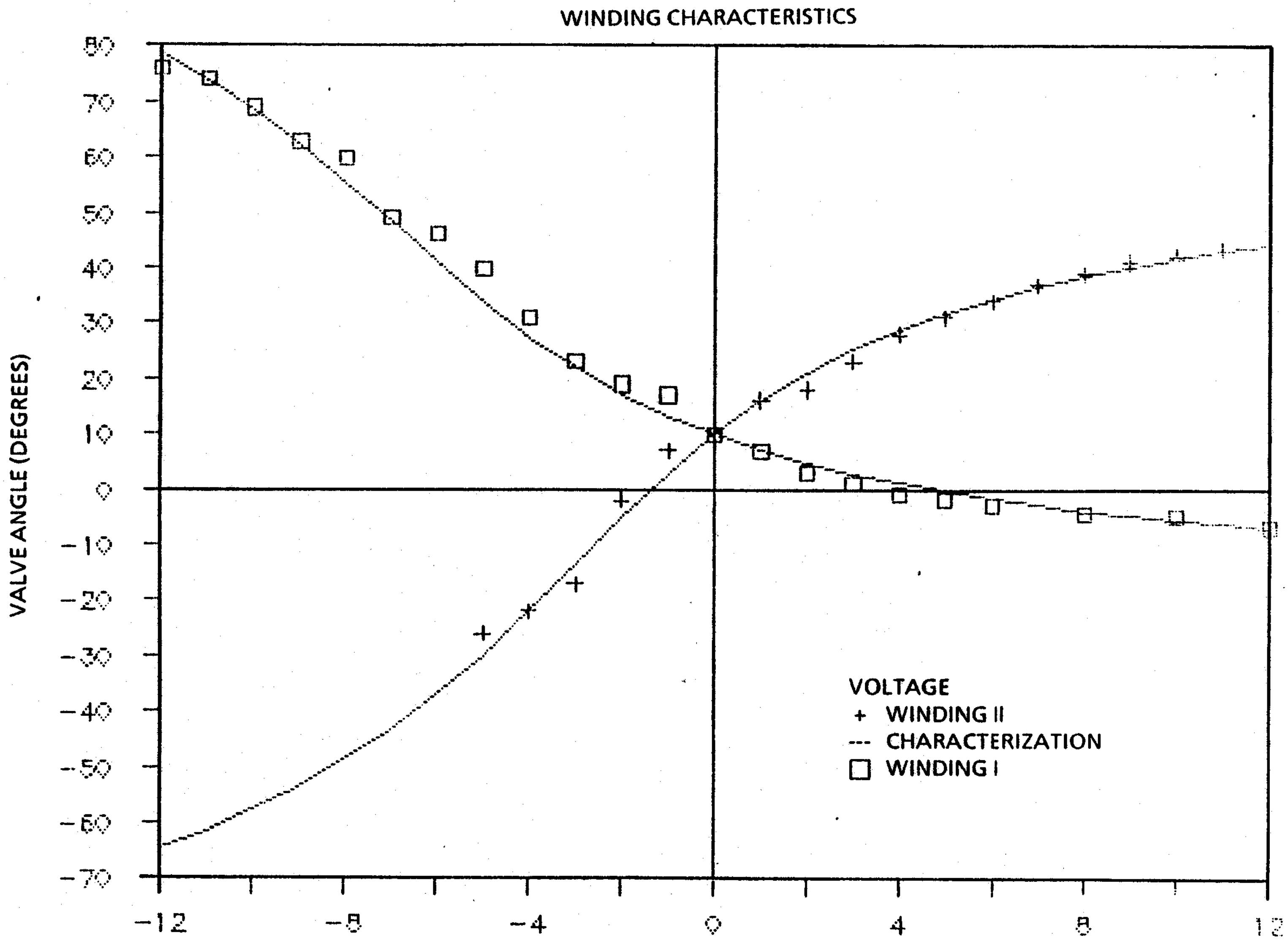


FIGURE A-2. ARMATURE FIELD WINDING CHARACTERISTICS MEASURED AND ESTIMATED

The general equation of motion for the valve is : [A.4]

$$M=-T_s+T_1+T_2=I\frac{d^2(\theta)}{d(t)^2}$$

where

I = moment of inertia

and [A.5]

$$V_T=V_1+V_2=12\ volts$$

Voltages V_1 and V_2 are time-averaged voltages.

The torque-contributing components were combined to determine the angular displacement of the valve, keeping $V_1 + V_2 = 12$ V and a settled valve (i.e., not being commanded to a new position). The torques developed in the valve due to the airflow are not included in the equations since these torques are negligible compared to the winding torques.

The resulting valve equilibrium equation is:

[A.6]

$$M=0=-K_s(\theta-10)+K_1V_1sin(\theta-\theta_1)+K_2V_2sin(\theta-\theta_2)$$

The result plotted in Figure A-3 represents the opening angle of the valve as a function of the percent duty cycle on Winding I during normal operation. Measurements made to confirm these positions for the different duty cycles are shown as the symbols in Figure A-3. The characterizations of the torque-contributing components were used to establish the relationship between the torque acting on the valve armature and the valve angular displacement. Under normal operation, the equilibrium positions range between -7° to the fully open position of 44°. When the valve reaches the 44° position, further opening does not increase the airflow. However, if the valve goes beyond the -36° position (past fully closed), the valve begins to increase the airflow again.

The control unit supplies 12 V to the center pin and adjusts the average current sent to the valve armature by alternately grounding either pin 1 or pin 3. The time period that the computer grounds the pins defines the duty cycle. Pins 1 and 3 are connected to brushes that run against a segmented commutator of the armature. Figure A-4 shows the orientation of the valve's electrical components, and the sign and naming conventions. A diagram of the electrical circuit within the armature for normal operation is shown in Figure A-5(a).

The arrows in Figure A-5(b) represent the direction of current flow under normal operation. A 12 V power is supplied to the positive collector segment and the pins 1 and 3 are grounded by the control unit to complete the circuit. The grounding of pin 3 is the command to open the valve fully. Figure A-6 shows the torque acting on the valve armature as a function of valve opening angle for the fully open command. This curve shows that if the valve was at the 10° equilibrium position and received this command, a torque of 9.6 oz-in would be applied to the armature with a final settling position of 44°. The grounding of pin 1 is the command to fully close the valve. Figure A-7 shows the torque acting on the valve armature as a function of valve opening angle for the fully closing command. This curve shows that if the valve was at the 10° equilibrium position and received this command, a torque of -4.5 oz-in would be applied to the armature with a final settling position of -7°. The major discontinuities in these curves at the 94 and -26° positions result from the brushes contacting the adjacent commutator segments.

The armature is not mechanically restricted to 120° of travel so the brushes can contact adjacent commutator segments. Since the valve may overshoot the position commanded by the controller, there is a potential for the armature to overrun the commutator segment. If this were to occur, the current in the windings would change direction and, in turn, reverse the torque applied.

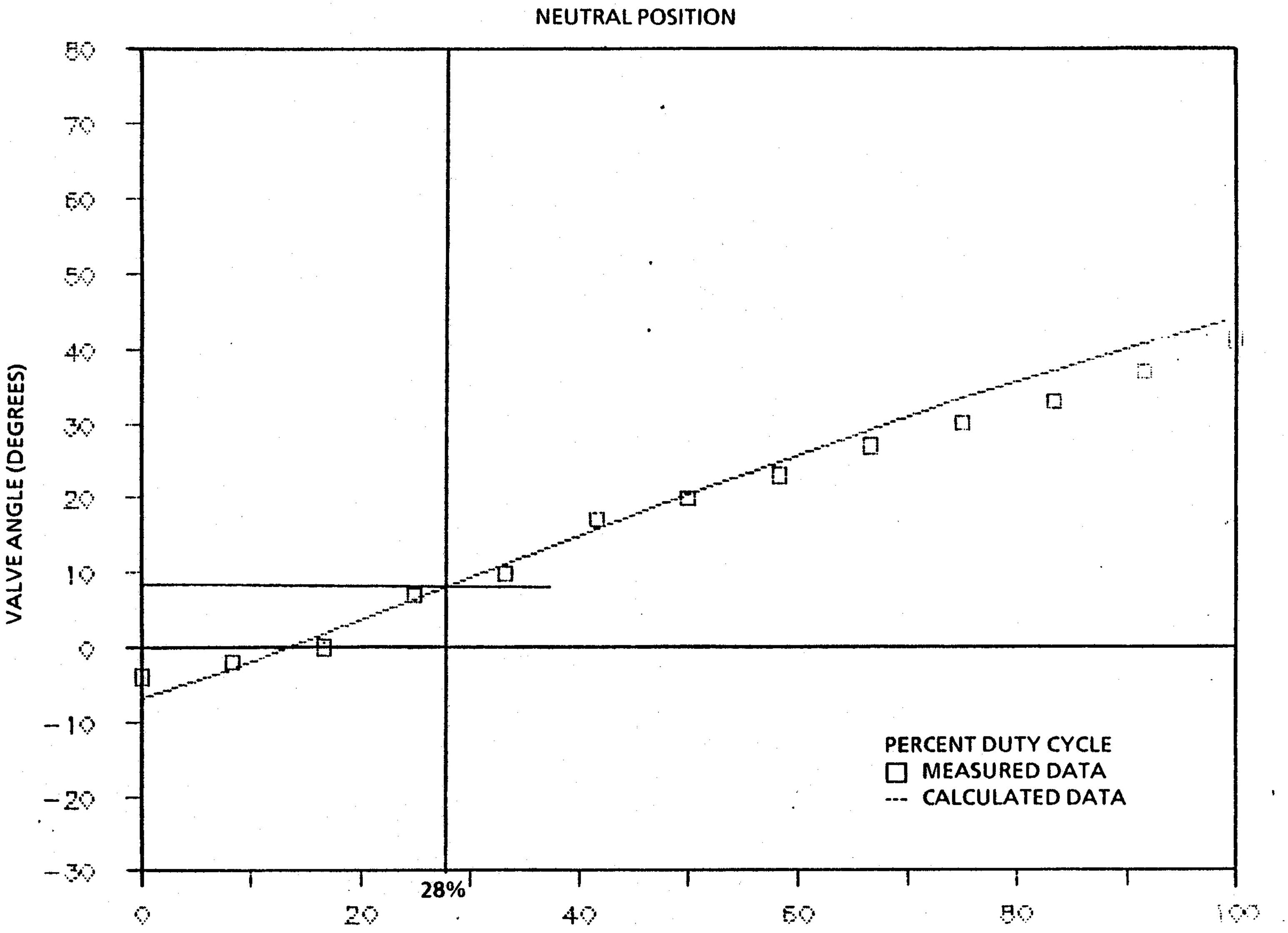


FIGURE A-3. OPENING ANGLE OF VALVE AS A FUNCTION OF PERCENT DUTY CYCLE ON WINDING I DURING NORMAL OPERATION

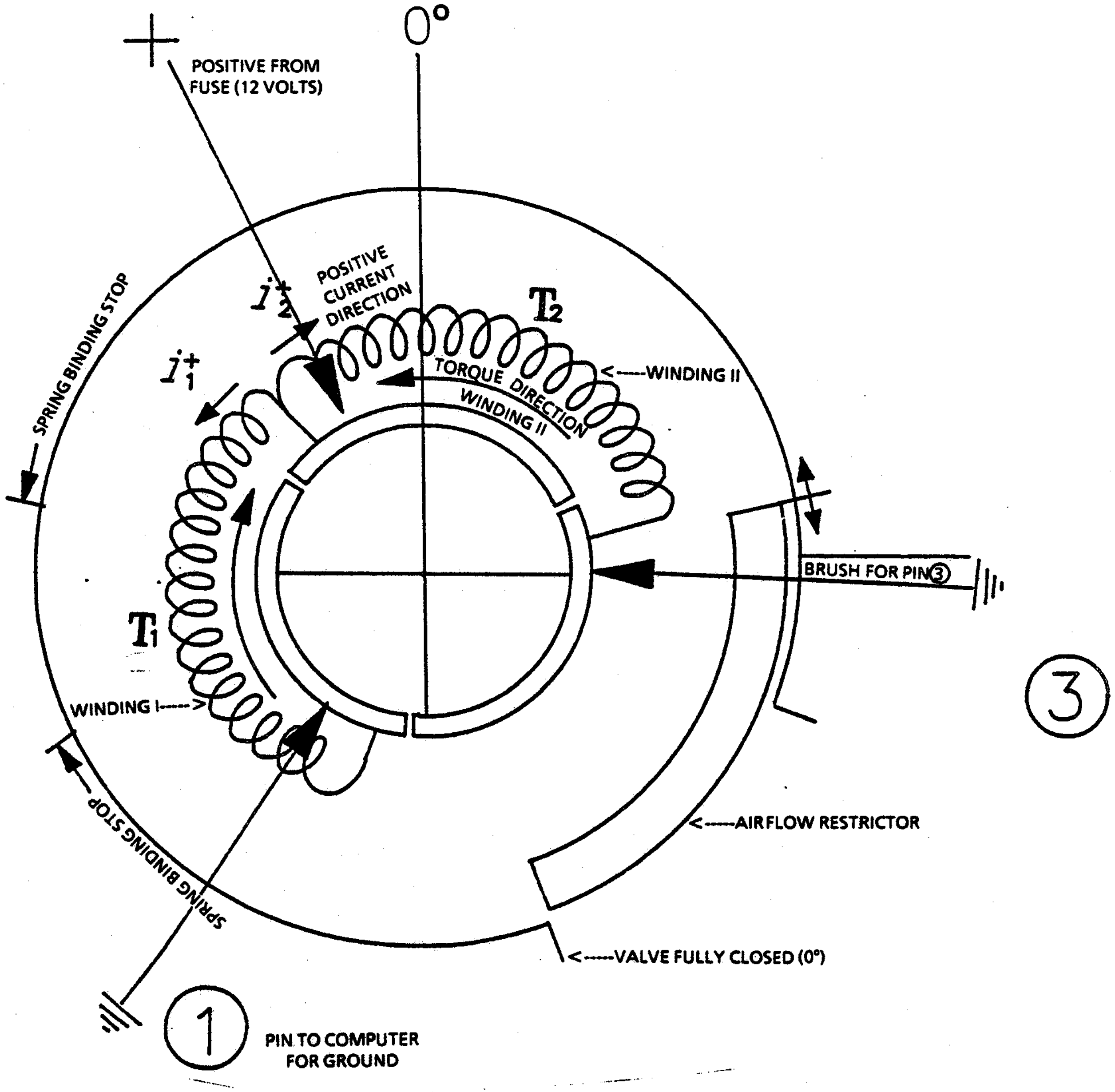
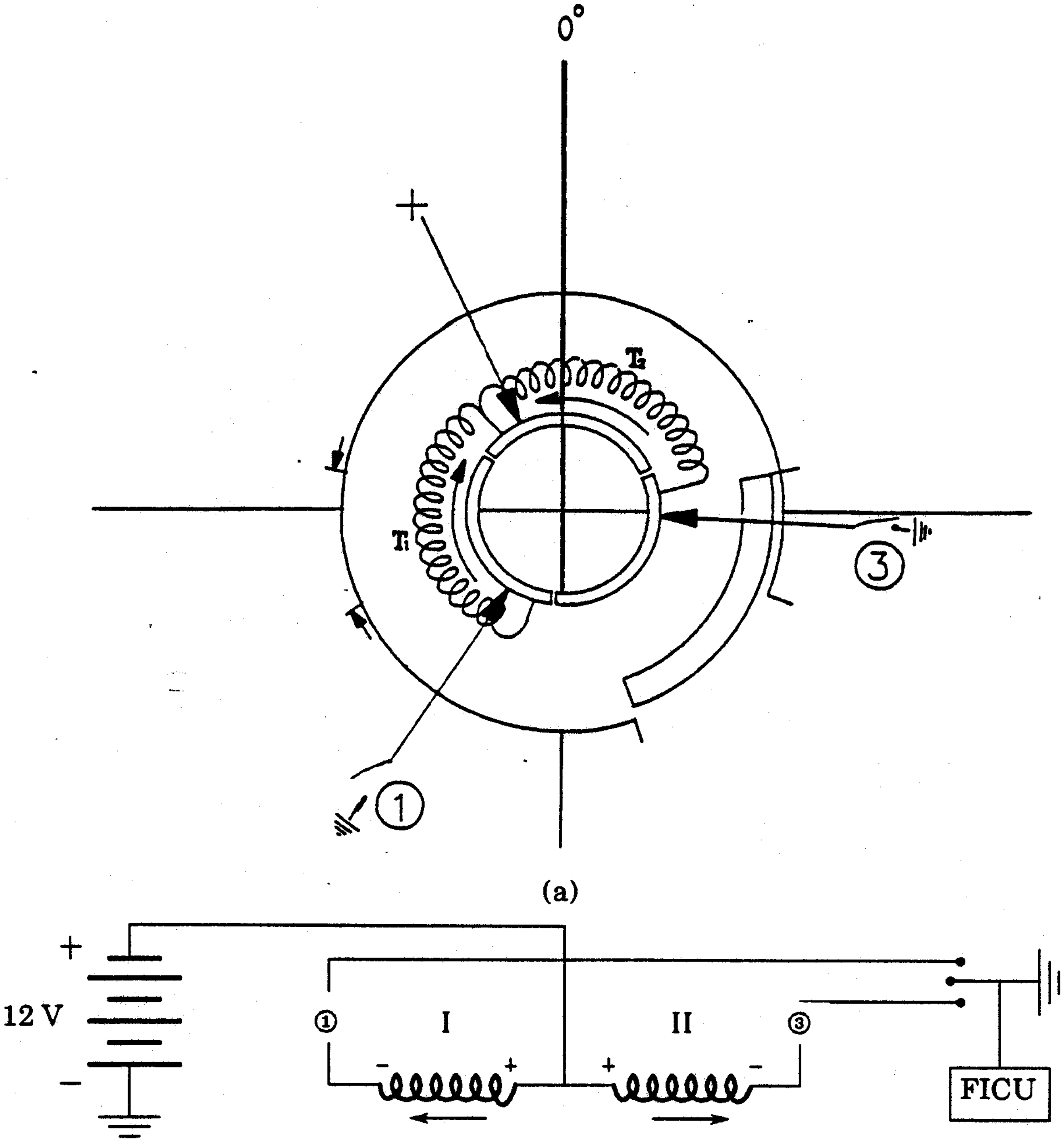


FIGURE A-4. ORIENTATION OF VALVE COMPONENTS AND SIGN CONVENTIONS

NORMAL



(a)

(b)

FIGURE A-5. IDLE-STABILIZER VALVE UNDER NORMAL OPERATION

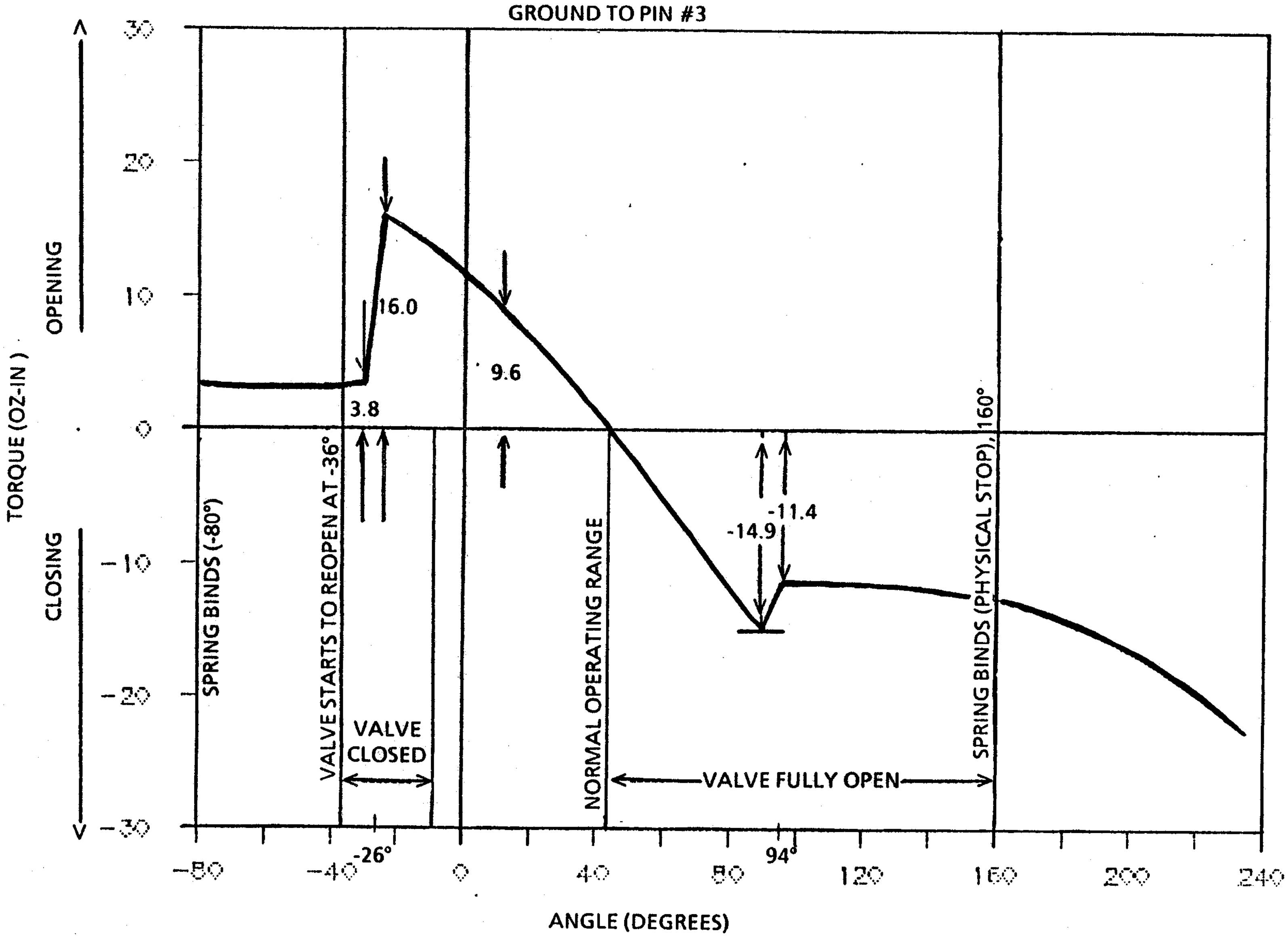


FIGURE A-6. TORQUE ON ARMATURE VERSUS VALVE OPENING ANGLE FOR THE COMMAND TO FULLY OPEN

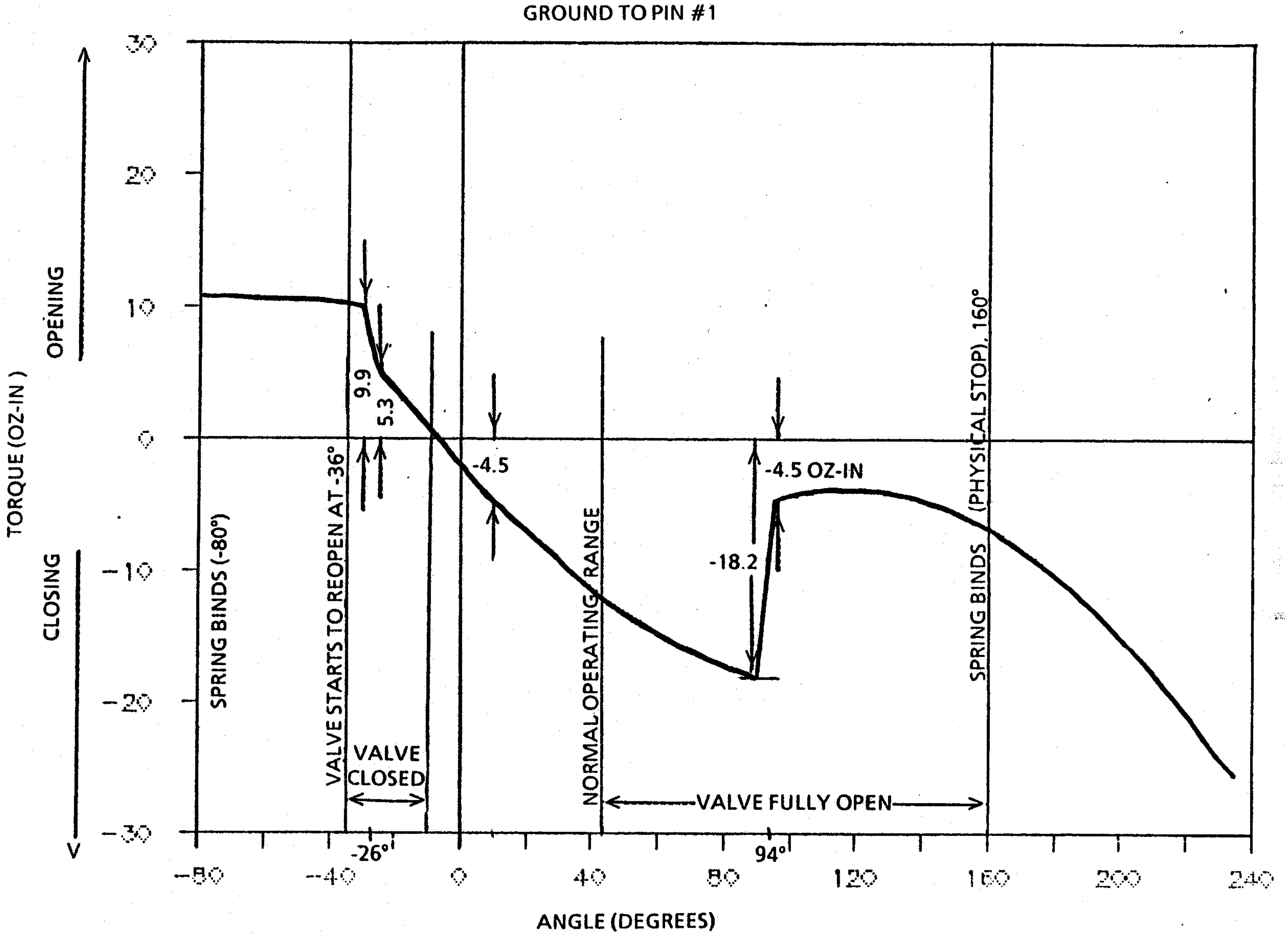


FIGURE A-7. TORQUE ON ARMATURE VERSUS VALVE OPENING ANGLE FOR THE COMMAND TO FULLY CLOSE

The two possible overrun positions are the overrun open and overrun closed positions. In Figure A-8 the electrical circuit is shown for the case just before the overrun open condition occurs ($\theta < 94^\circ$). The current flow is the same as under normal operation. When the overrun open condition occurs ($\theta > 94^\circ$), the electrical circuit in the armature is affected as shown in Figure A-9(a).

As shown in Figure A-9(b), the current reverses direction in Field Winding II. This change in direction reverses the direction of the torque applied. The current in Field Winding I is in the same direction as normal operation. This torque reversal causes the torque in the closing direction to decrease. If the computer should send a command to fully open (pin 3 being grounded, 100 percent duty cycle) while the valve is in the overrun open position, the torque changes from -14.9 oz-in to -11.4 oz-in, as shown in Figure A-6. In the case of a command to fully close (pin 1 being grounded, 0 percent duty cycle), the closing torque would change from -18.2 oz-in to -4.5 oz-in, as shown in Figure A-7.

For the cases of overrunning in the closed position ($\theta < -26^\circ$), the electrical circuit in the armature is affected as shown in Figure A-10. As the current changes direction in Field Winding I, the torque changes direction. The change in direction increases the opening torque. For the fully closed command, the opening torque changes from 5.3 oz-in to 9.9 oz-in (Figure A-7). For the fully open command, the opening torque decreases from 16.0 oz-in to 3.8 oz-in (Figure A-6).

A.2 TRANSIENT RESPONSE

When the valve responds to a change in duty cycle, the valve will overshoot the equilibrium position by an amount approximately equal to the initial displacement error. Figure A-11 shows how a simple spring mass system would overshoot in response to an initial displacement. The equilibrium position is the position to which the valve would settle if no other duty cycle was encountered. If the duty cycle was changed suddenly to command a new valve opening angle, the valve would overshoot the new equilibrium position by an angle approximately equal to the difference between the old angle and the new position. If the engine's change in RPM response time is slow, the difference between the new and old angle can become large and increase the possibility of overrun conditions.

A.3 POTENTIAL FAILURE MECHANISMS

It was necessary to determine if there was a mechanical sticking that would hold the valve in the fully open position. Mechanical sticking could be caused by either a bearing failure or a brush commutator failure. In the event of a bearing failure, the valve opens fully and remains open because of the binding of the bearing on the shaft. In the event of the brush commutator failure, the brush would attach itself to the current collector. If the valve was under the overrun open condition and a mechanical-resisting torque of 4.5 oz-in existed, the closing duty cycle would not close the valve. The valve would remain above the 94° position as long as the closing duty cycle is being sent. Reversibility of this type of failure is very low. Under both of these mechanical failures the valve would not function properly and physical evidence of a defective valve would remain. If the valve was in the overrun open position and all components functioned properly, the valve would always return to the equilibrium position.

The idle-stabilizer valve could possibly fail if the commutator developed a dead spot and caused an intermittent opening of the circuit. This intermittent opening would cause a large oscillation from a fully closed to a fully open position. Such continuous oscillation would produce engine surging and might also produce a fatigue failure of the spring.

If the spring was to fail due to large oscillations, the valve would still operate. Without the resisting torque of the spring the valve would respond faster to the signals present and have a greater tendency to overrun the commutator. Within the normal range the valve characteristics are similar to normal

JUST BEFORE OVERRUN OPEN ($\theta < 94^\circ$)

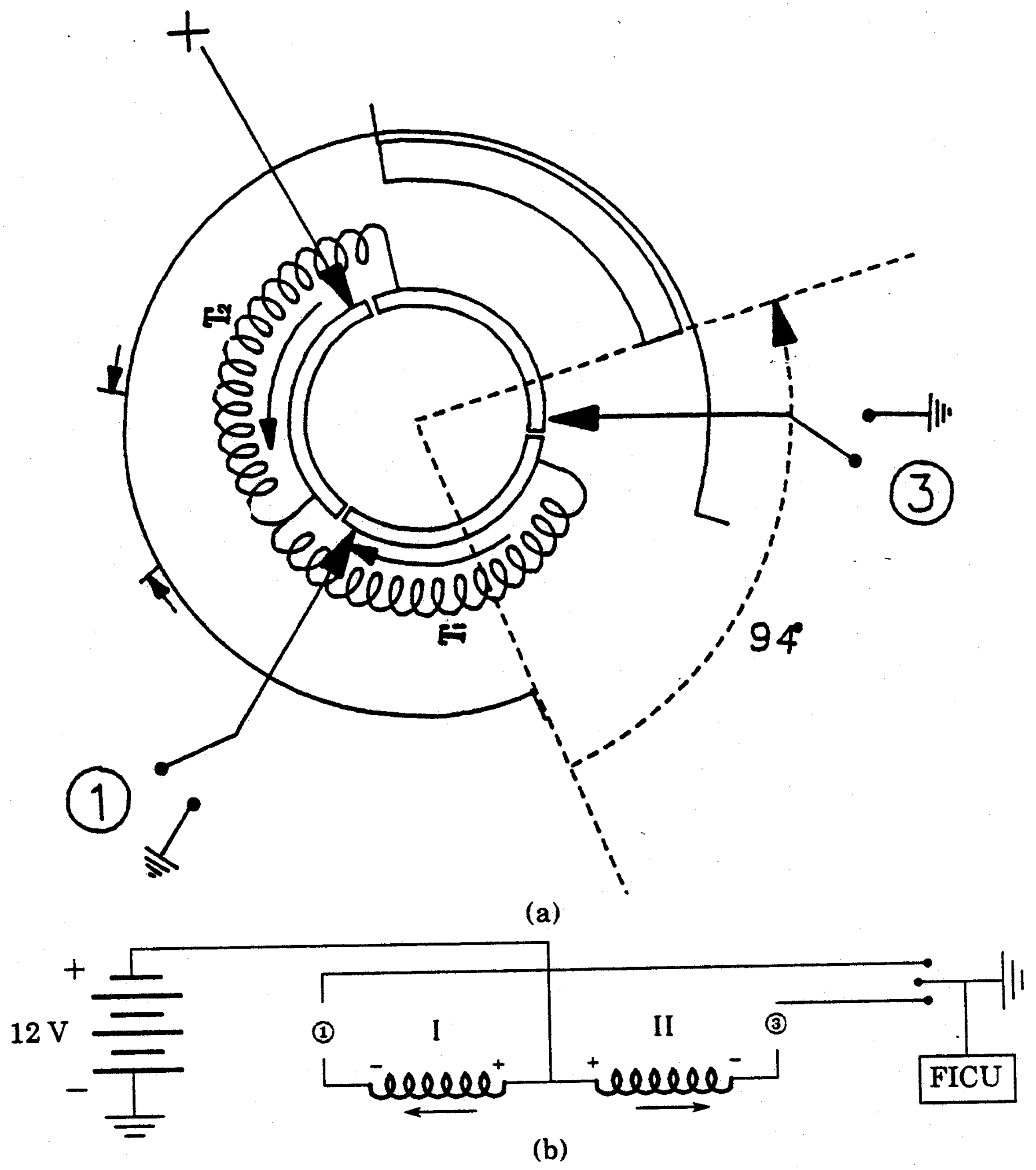
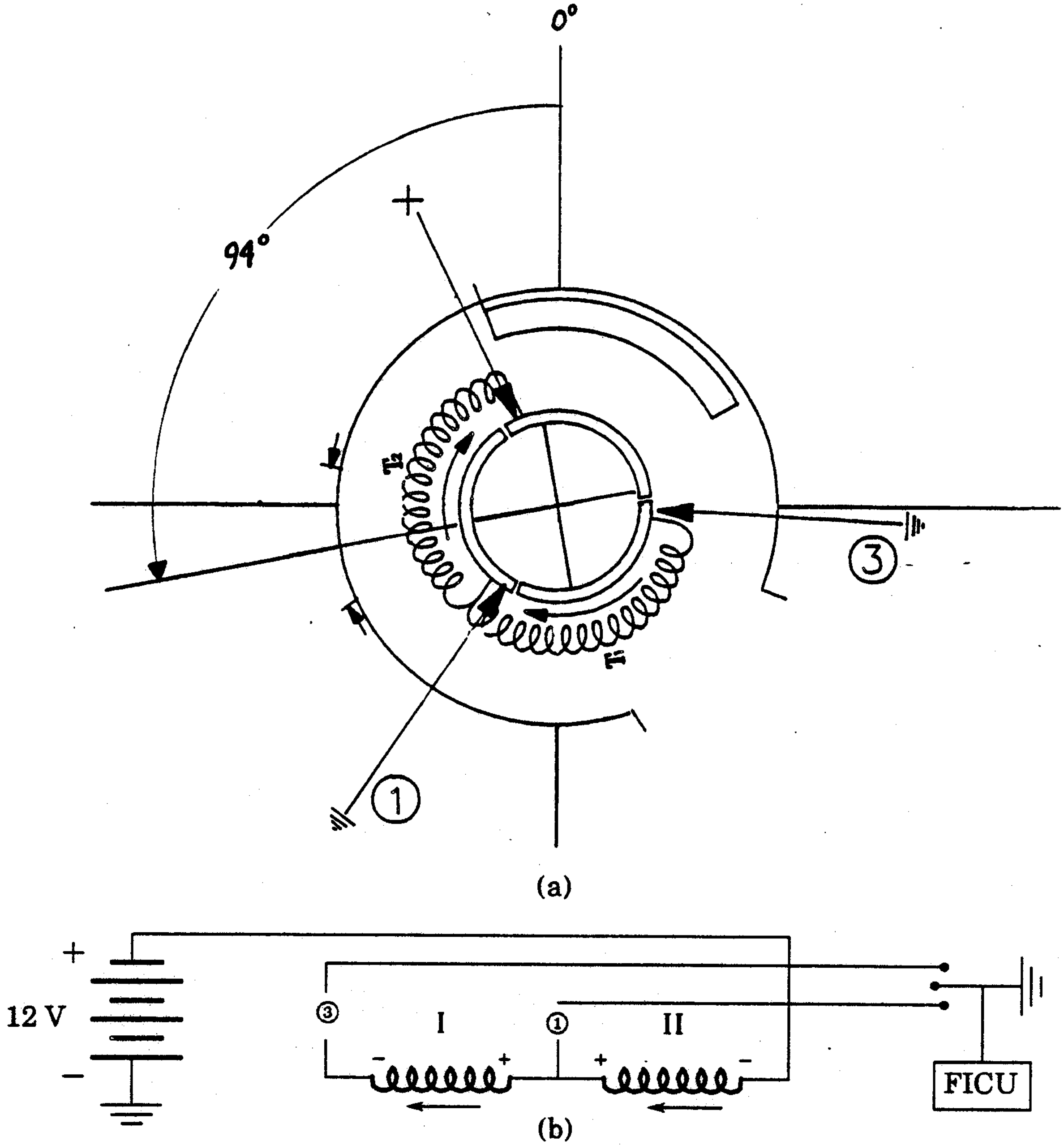


FIGURE A-8. IDLE-STABILIZER VALVE JUST BEFORE THE OVERRUN OPEN POSITION OCCURS

OVERRUN OPEN

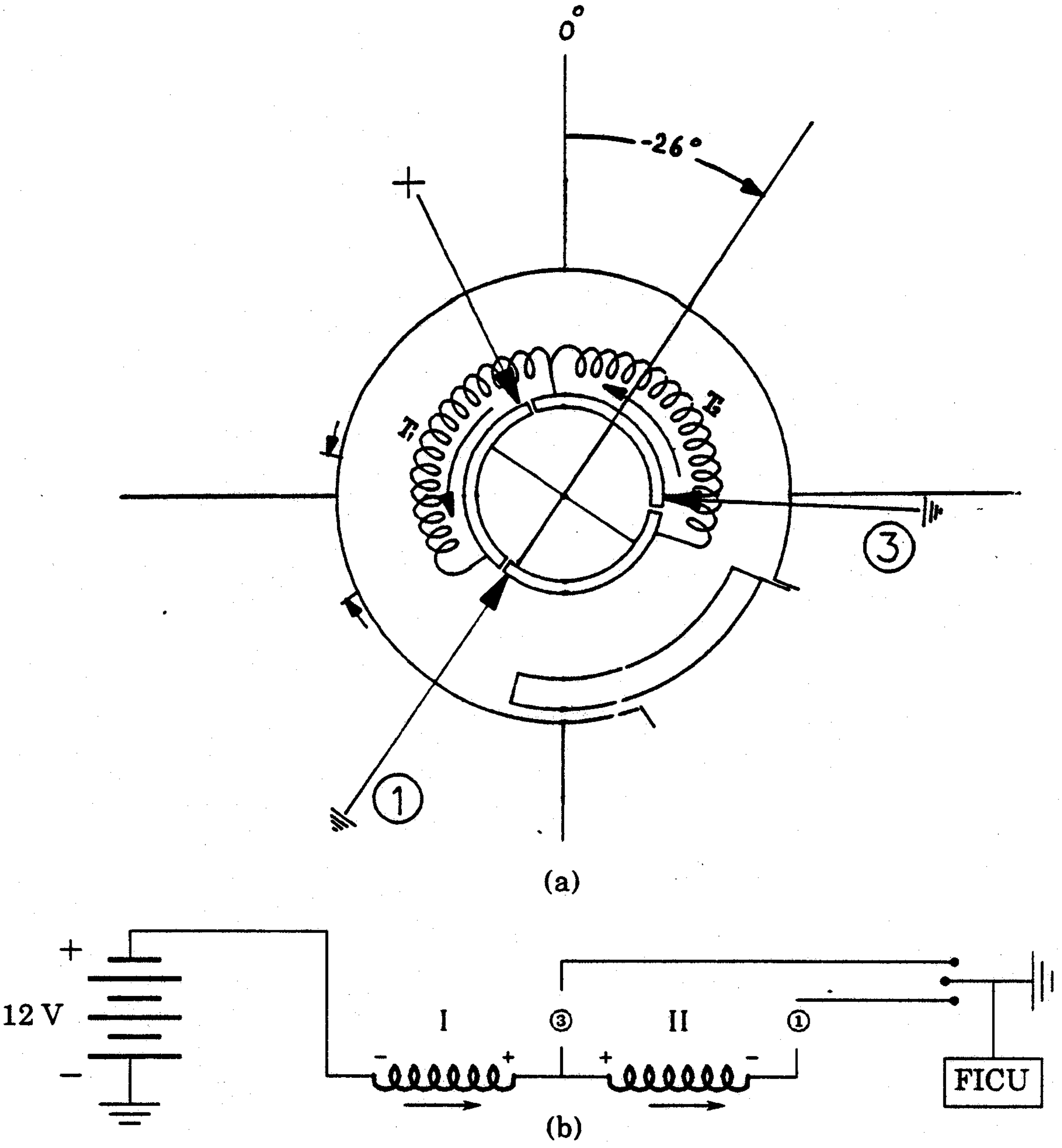


(a)

(b)

FIGURE A-9. IDLE-STABILIZER VALVE UNDER OVERRUN OPEN OPERATION

OVERRUN CLOSED



(a)

(b)

FIGURE A-10. IDLE-STABILIZER VALVE UNDER OVERRUN CLOSED OPERATION

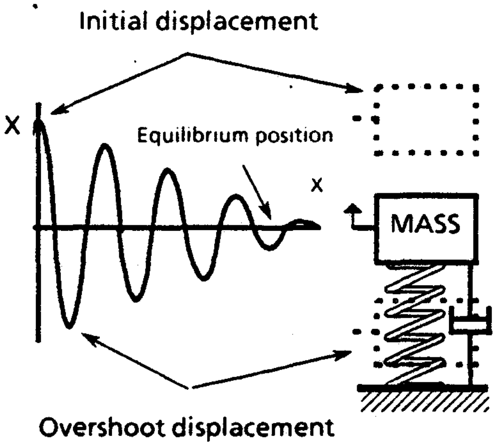


FIGURE A-11. SIMPLE SPRING MASS SYSTEM

operation. Figure A-12 shows the valve equilibrium opening angle as a function of duty cycle with the spring broken and with normal operation.

Figure A-13 illustrates the condition where the valve is commanded to fully open and the spring is broken. If the valve started at the 10° equilibrium position and received this command, the initial torque would be 9.6 oz-in. In this case, the valve would overshoot the commutator ($\theta > 94°$) and the closing torque would reduce from -4.8 oz-in to -1.0 oz-in. If the valve continued past the 104° position, the torque would become positive and cause the valve to open even further.

Figure A-14 shows the condition where the valve is commanded to fully close and the spring is broken. If the valve started above the 94° equilibrium position and received the command to close, the closing torque of -8.3 oz-in would change to an opening torque of 6.0 oz-in. This reversal of sign would cause the valve to continue to open even with a closing signal. If the spring was broken or defective and the valve was in the overrun condition, a normal closing signal would continue to open the valve. If the power was shut off after an overrun condition and the valve drifted to less than 94°, the valve would return to the broken spring operation when the power was turned on.

A broken spring in the valve would not hamper the performance of either the vehicle or the valve. The engine RPM might surge to a greater extent than normal, but this might not seem out of the ordinary. If the valve was tested according to the Audi Factory Repair Manual, the results could show normal valve operation. The test checks the engine RPM at the 28 percent duty cycle. As shown in Figure A-12, at the testing location of 28 percent, the difference in valve angle with and without the spring is about 2°.

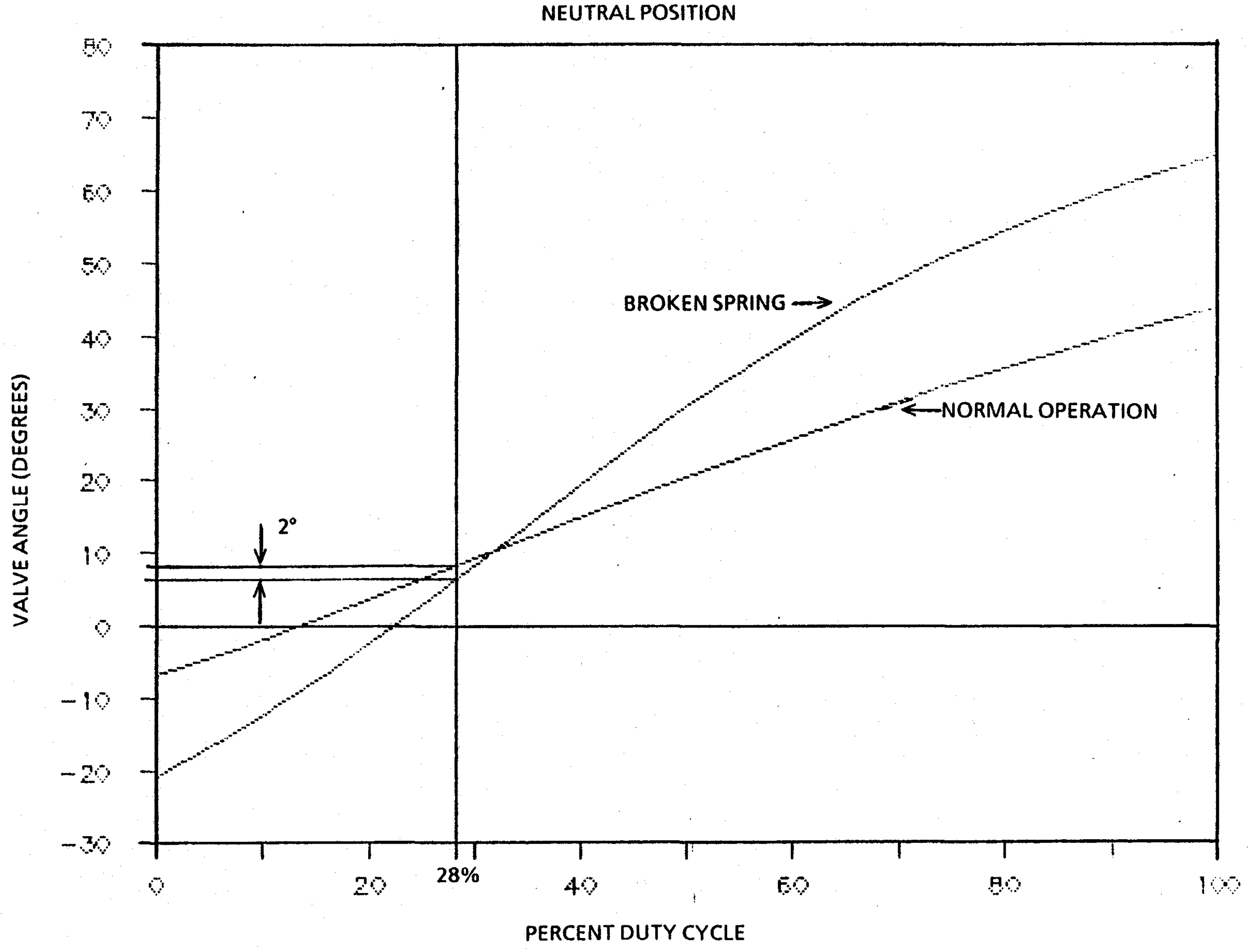


FIGURE A-12. OPENING ANGLE OF VALVE AS A FUNCTION OF PERCENT DUTY CYCLE ON WINDING I DURING NORMAL AND BROKEN SPRING OPERATION

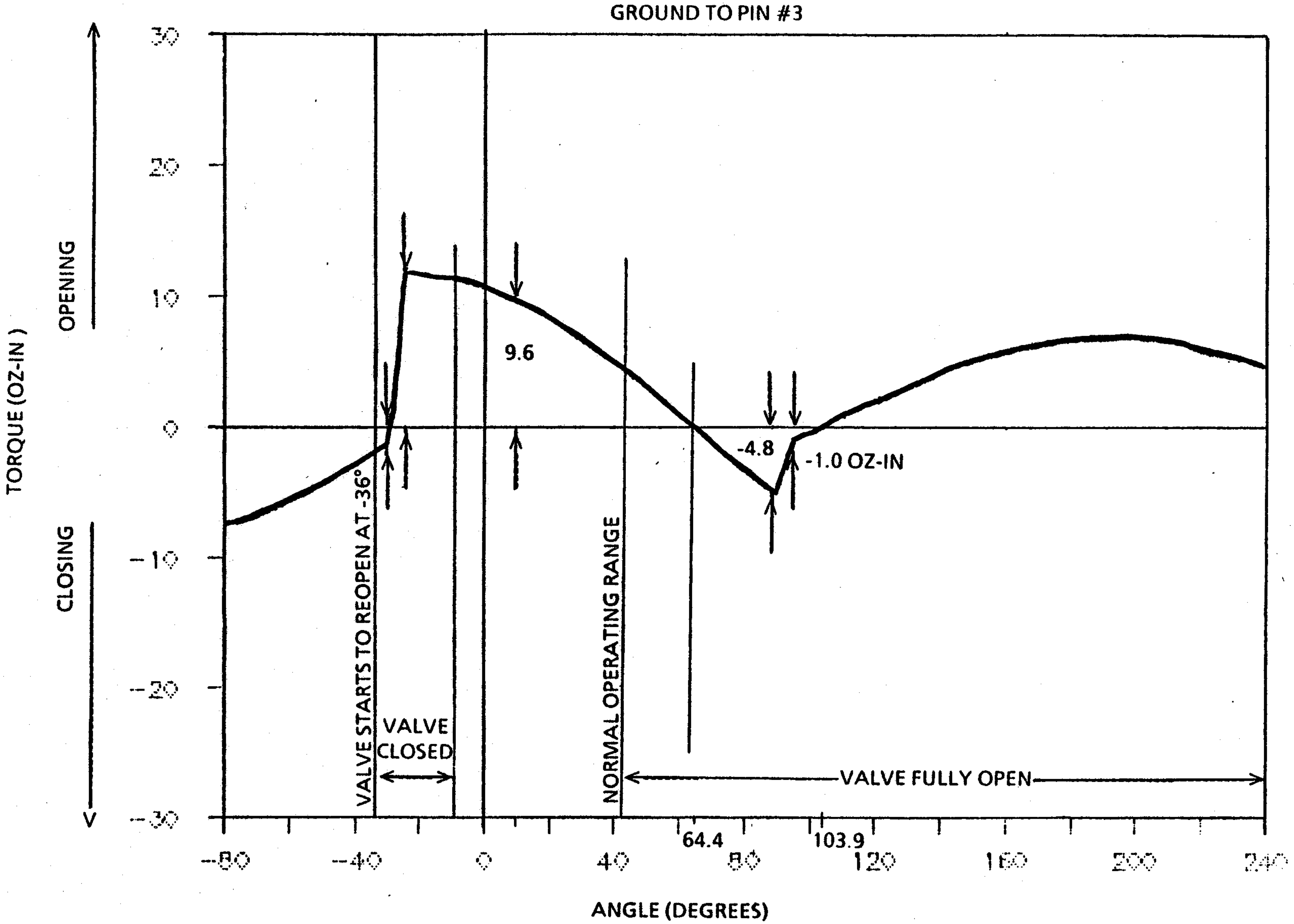


FIGURE A-13. TORQUE ON ARMATURE VERSUS VALVE OPENING ANGLE FOR THE COMMAND TO FULLY OPEN WITH SPRING BROKEN

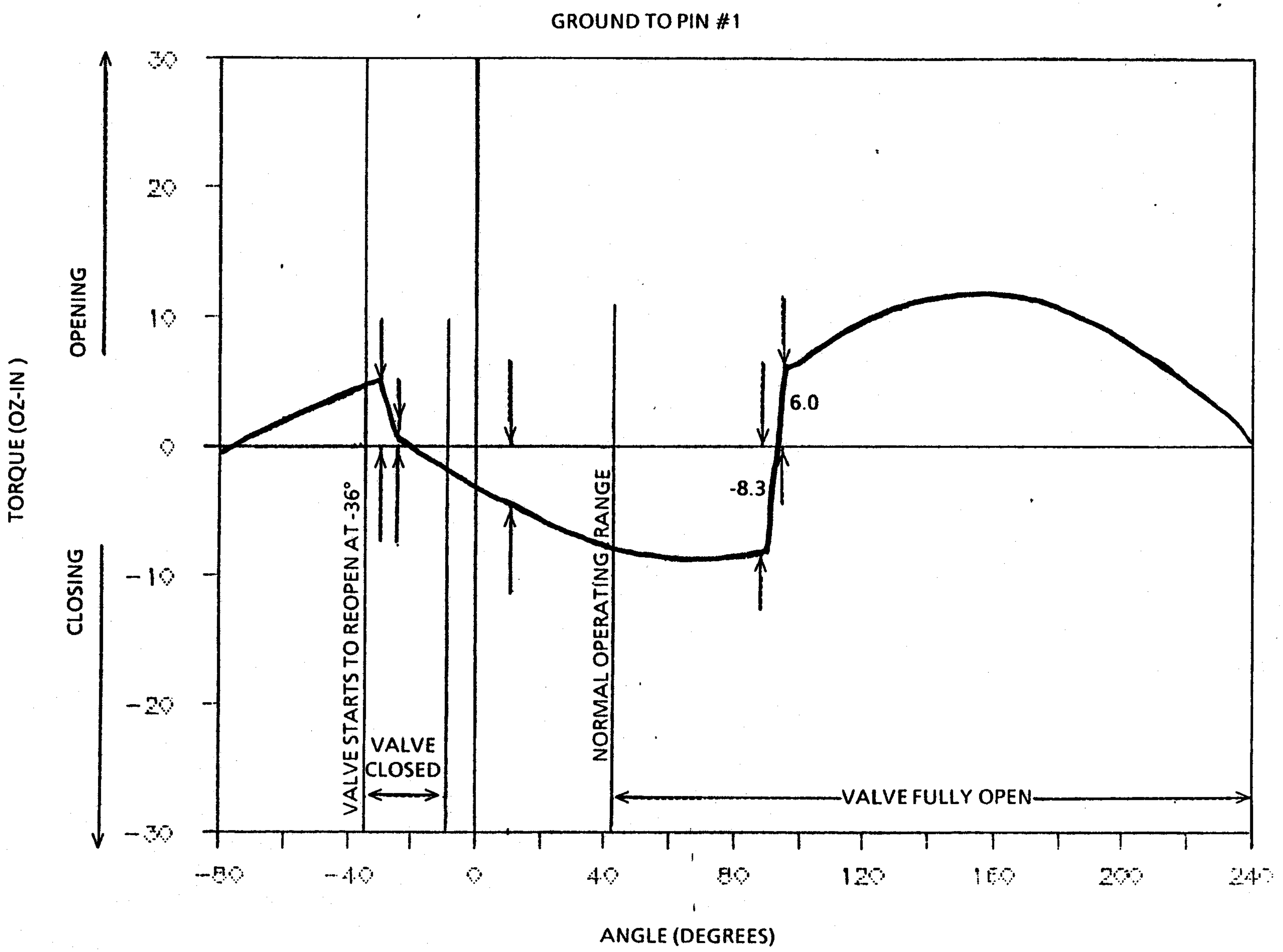


FIGURE A-14. TORQUE ON ARMATURE VERSUS VALVE OPENING ANGLE FOR THE COMMAND TO FULLY CLOSE WITH SPRING BROKEN

APPENDIX B

AUDI TEST DATA

Appendix B graphs are VWOA test data extracted from correspondence between NHTSA and VWOA.

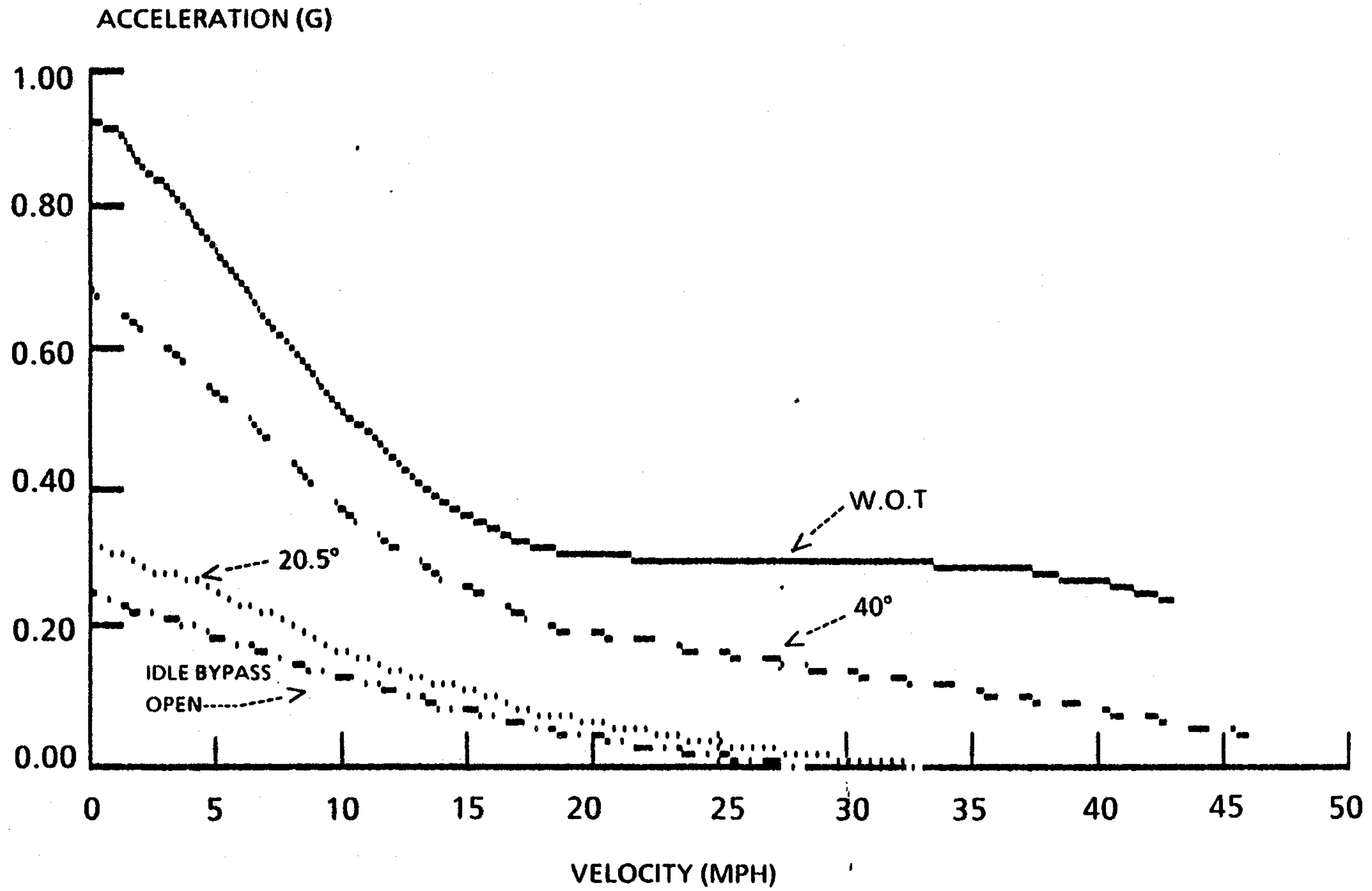


FIGURE B-1. 1986 AUDI 5000, REVERSE GEAR ACCELERATION (G) AT DIFFERENT THROTTLE ANGLES

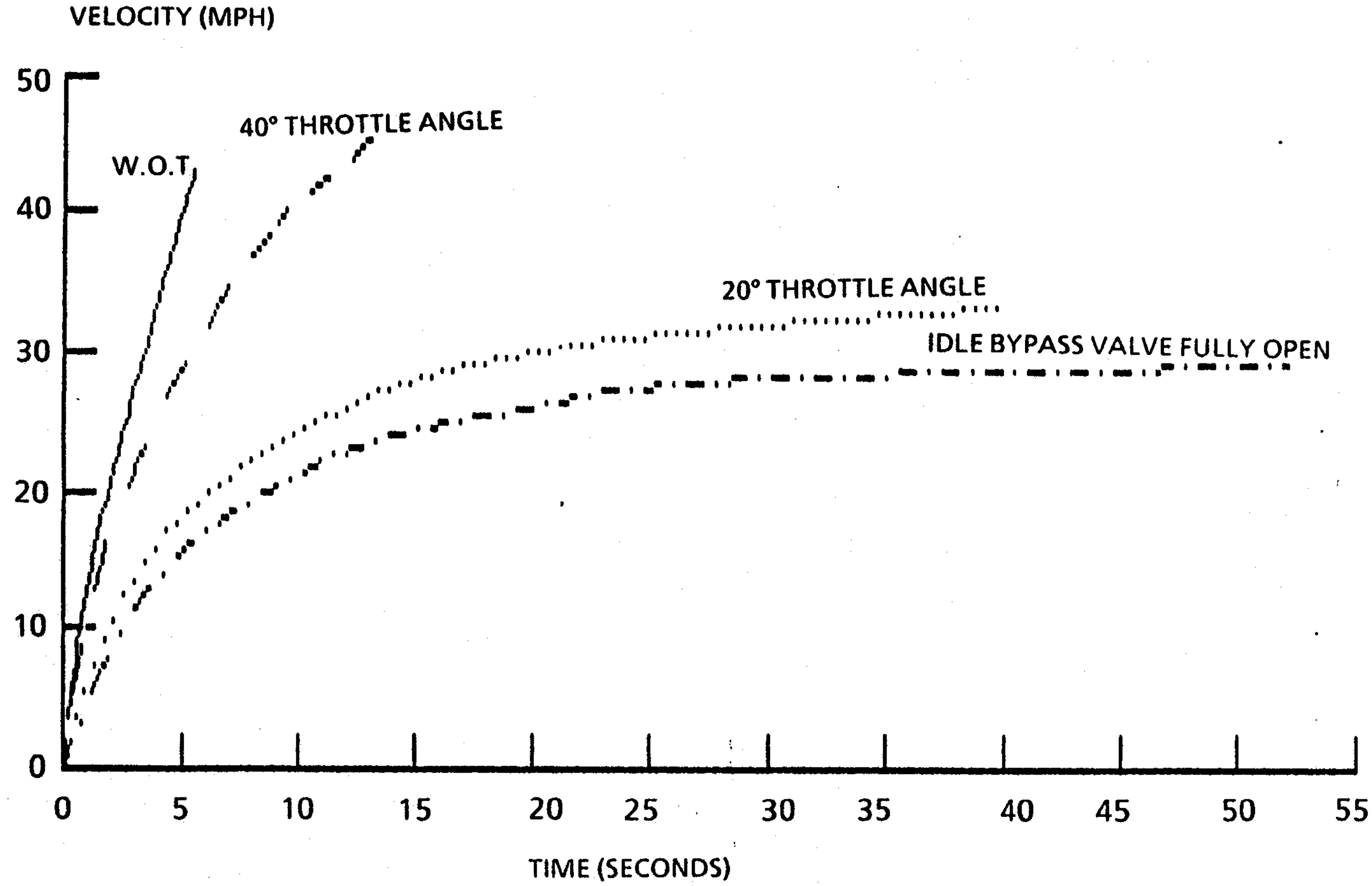


FIGURE B-2. 1986 AUDI 5000, REVERSE GEAR VELOCITY (MPH)/TIME

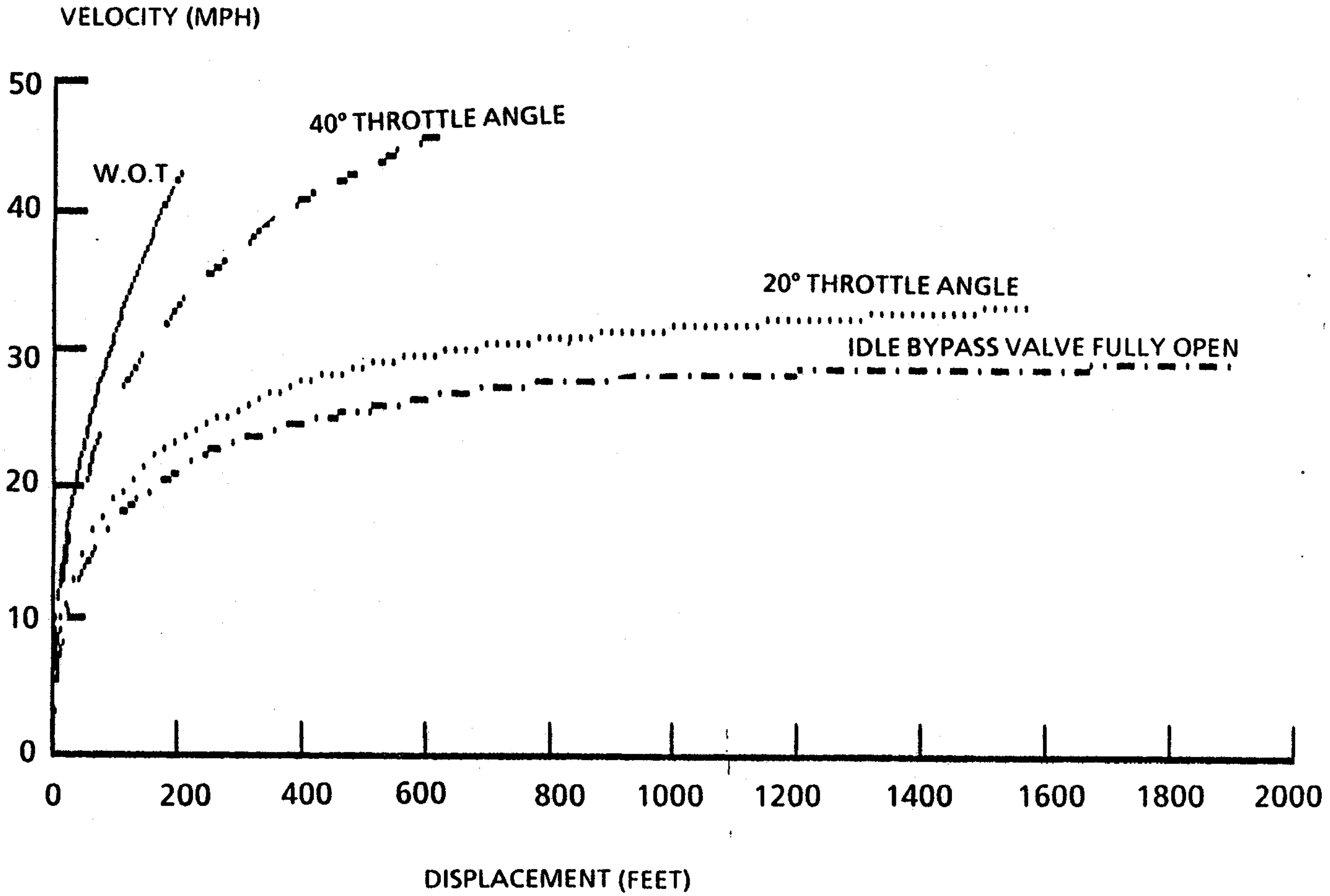


FIGURE B-3. 1986 AUDI 5000, REVERSE GEAR VELOCITY (MPH)/DISPLACEMENT

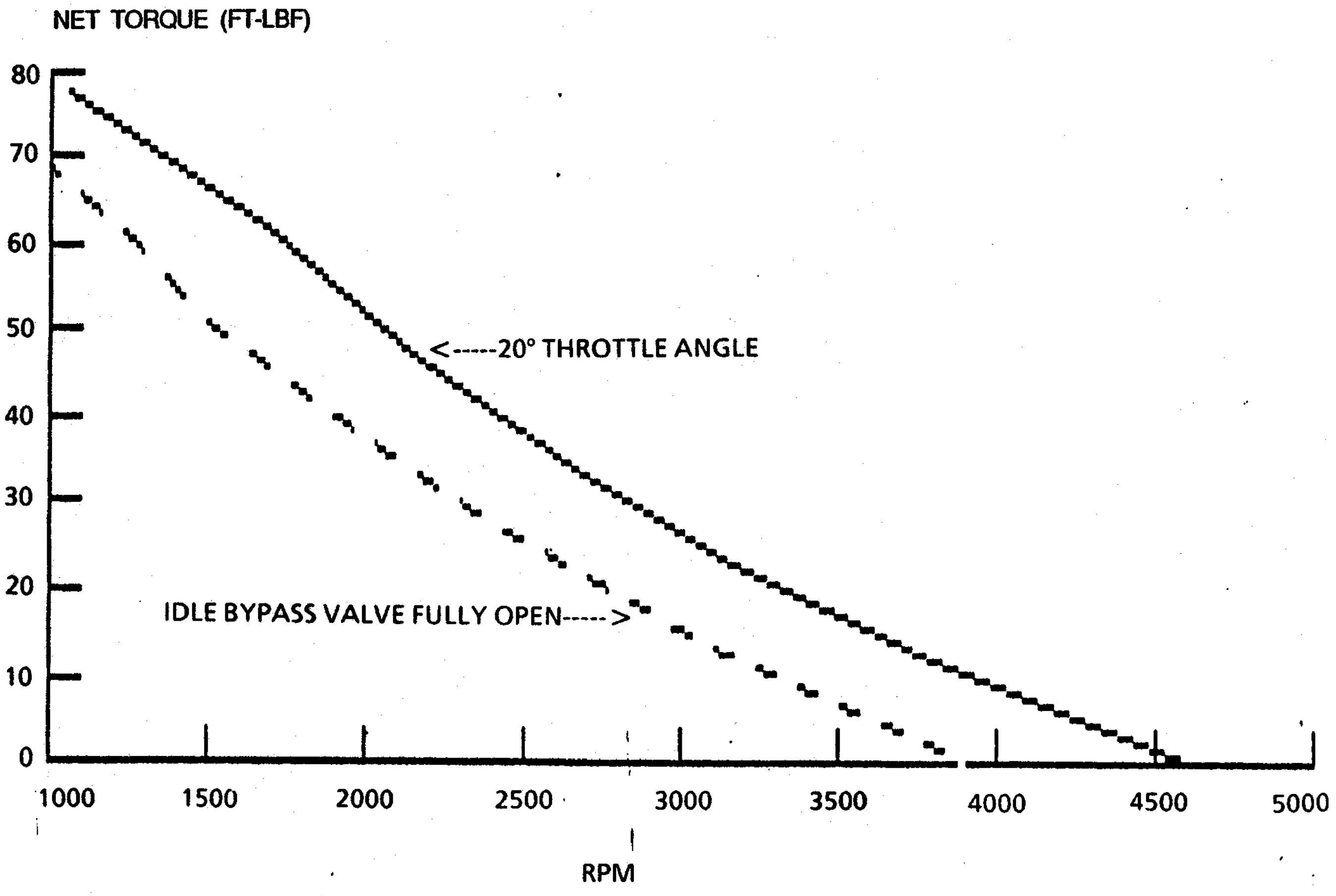


FIGURE B-4. NET ENGINE TORQUE (WARM)

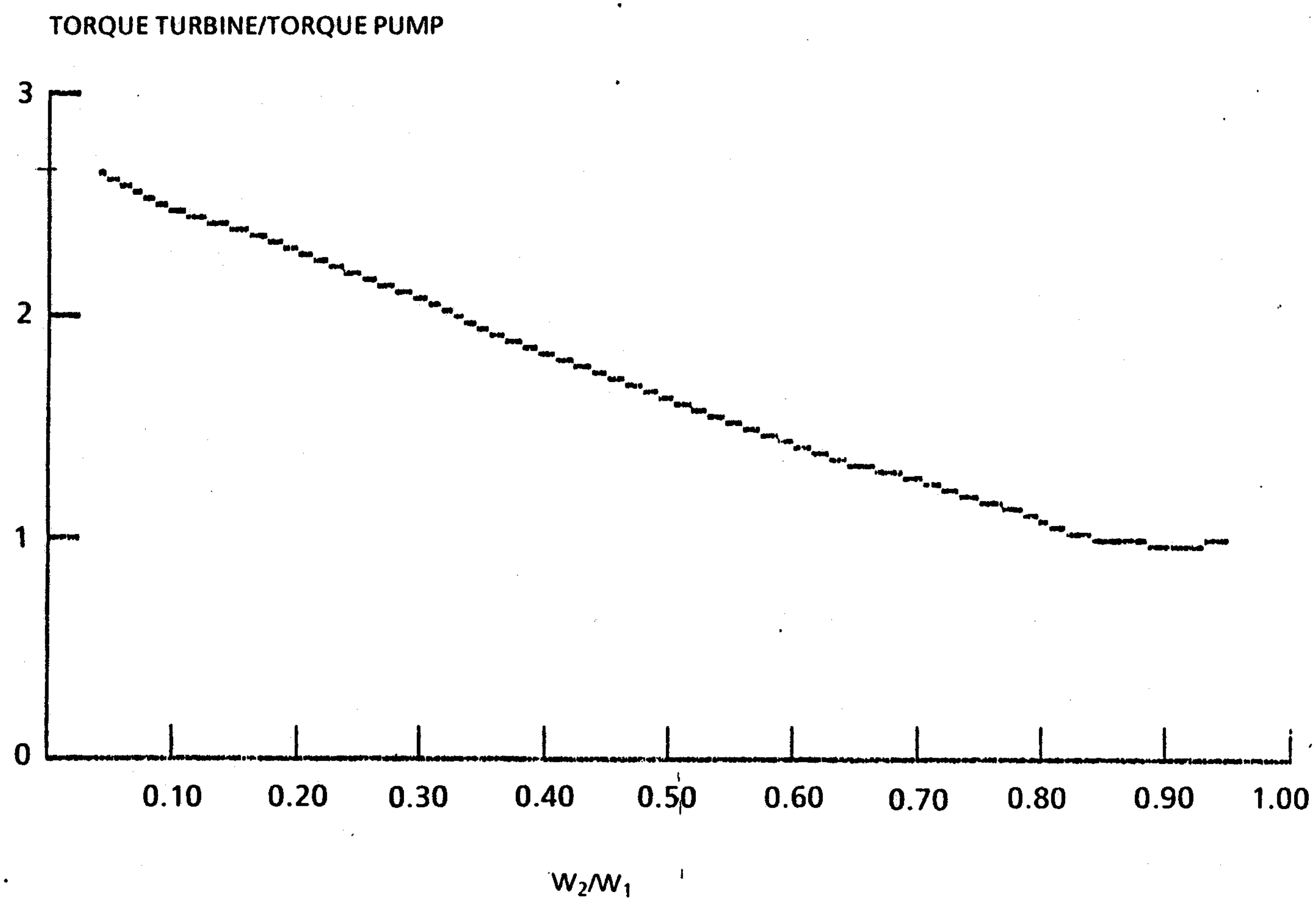


FIGURE B-5. TRANSMISSION TORQUE RATIO

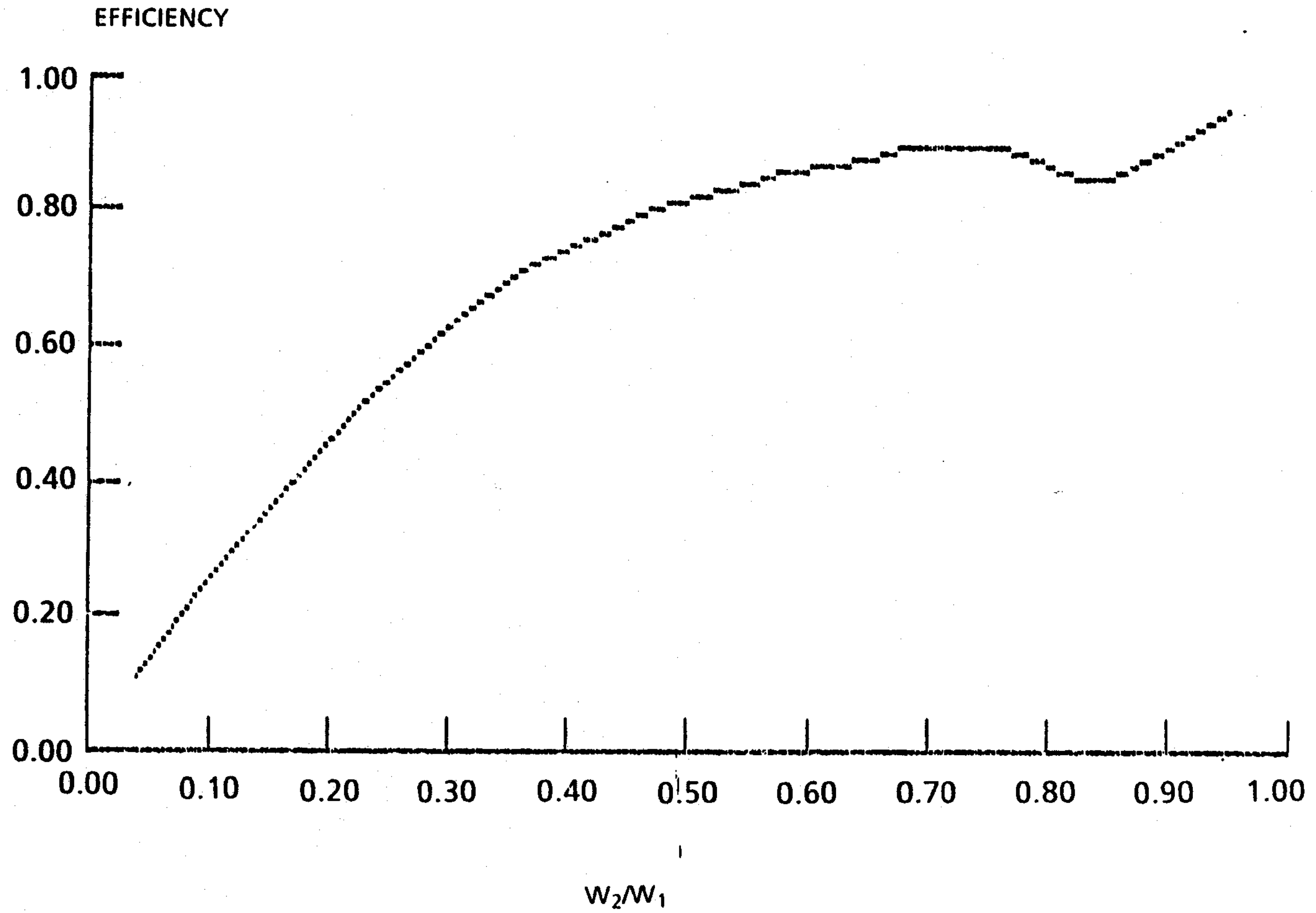


FIGURE B-6. TRANSMISSION EFFICIENCY

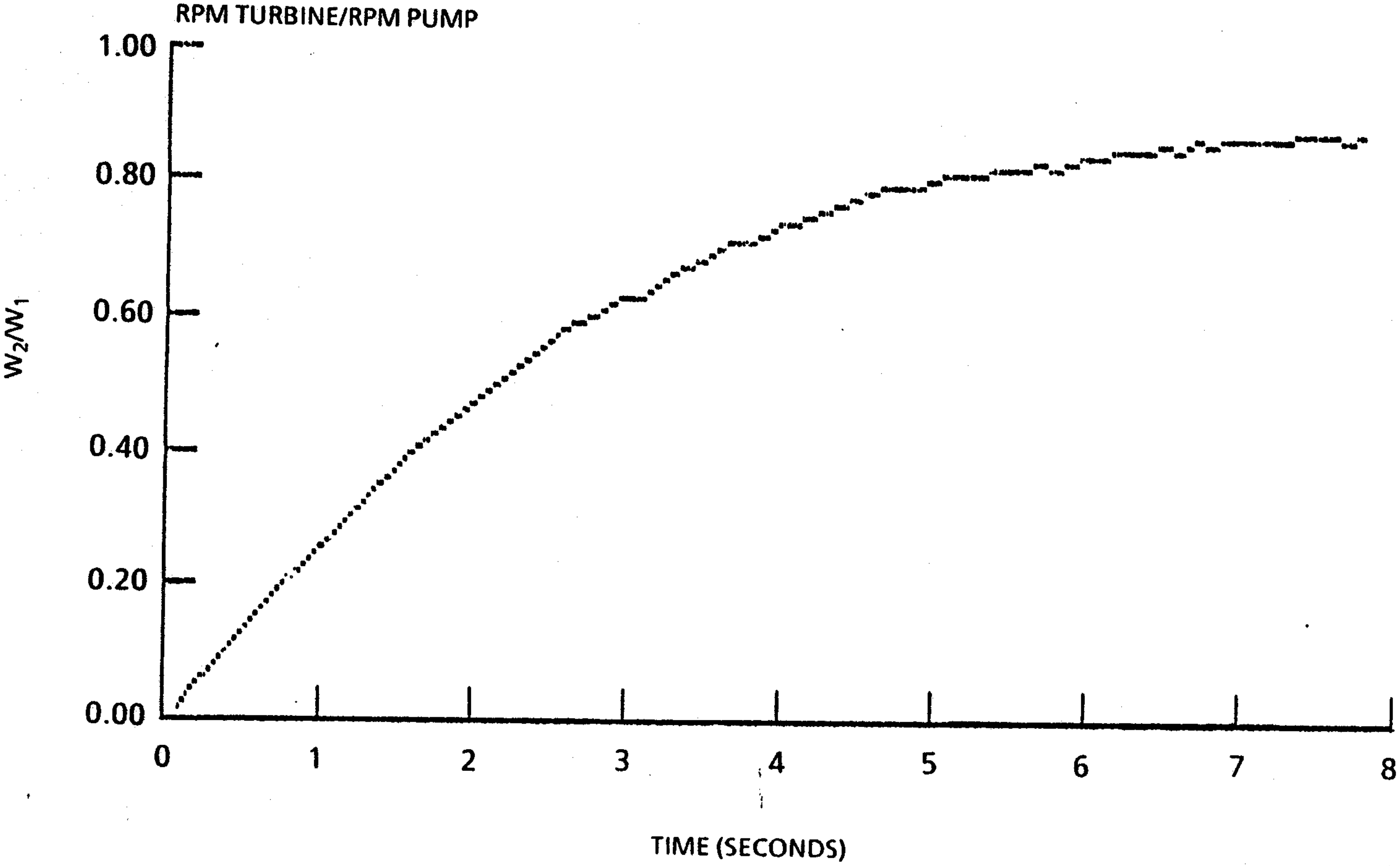


FIGURE B-7. RATIO OF ANGULAR VELOCITY, AUDI 5000S, REVERSE GEAR

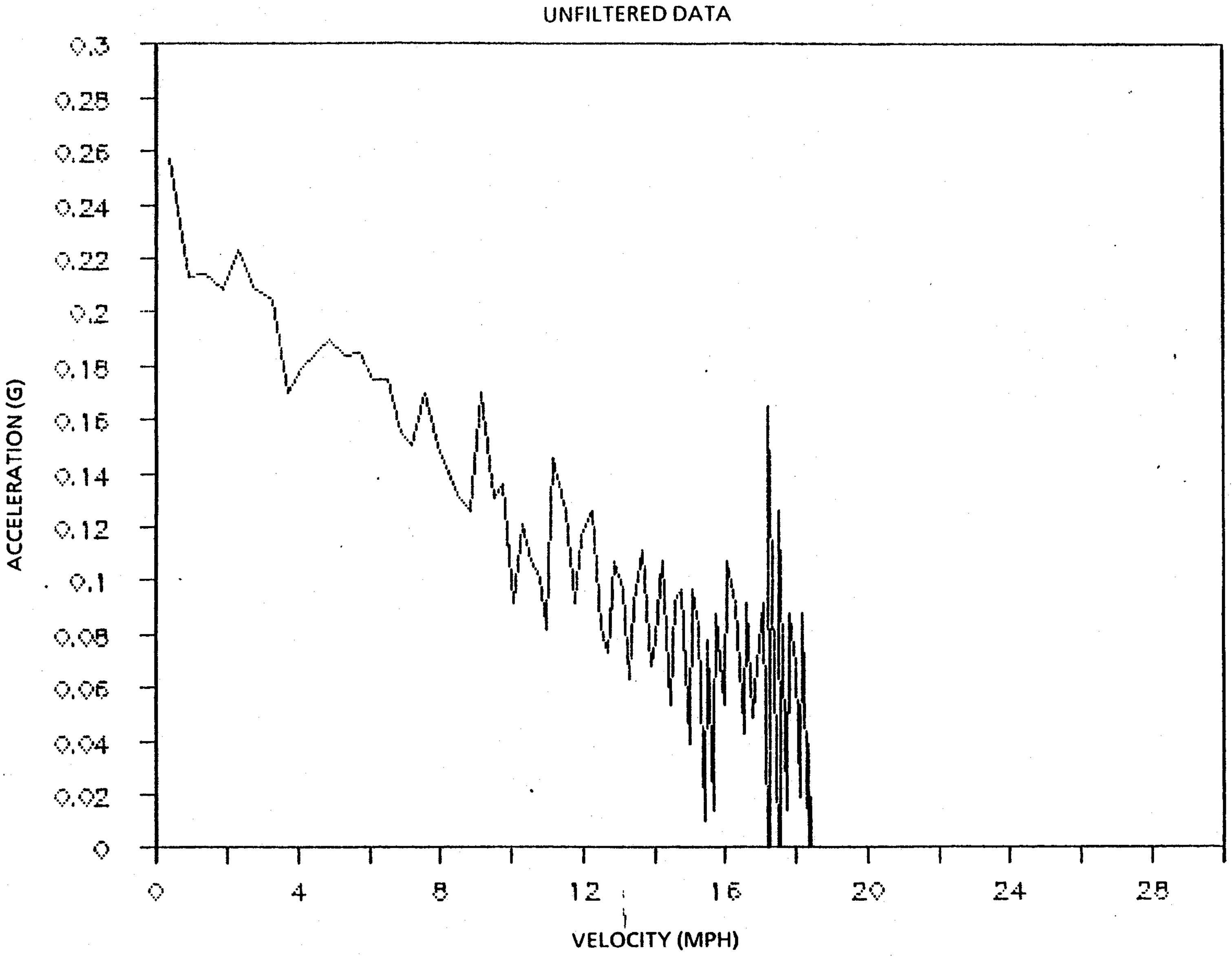


FIGURE B-8. VEHICLE ACCELERATION VERSUS VELOCITY, 1986 AUDI 5000S, REVERSE GEAR, IDLE-STABILIZER VALVE FULLY OPEN

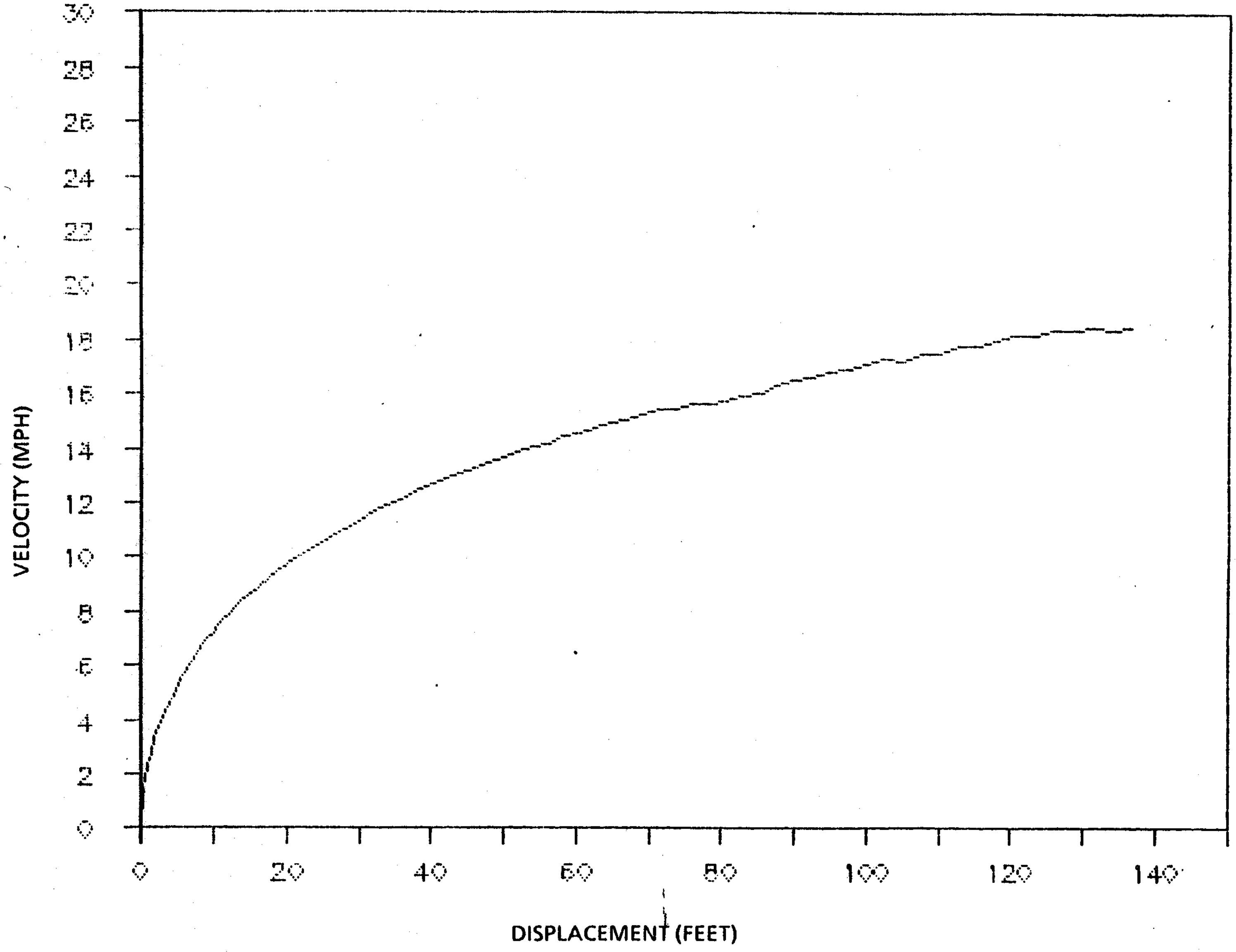


FIGURE B-9. VEHICLE VELOCITY VERSUS DISPLACEMENT, 1986 AUDI 5000S, REVERSE GEAR, IDLE-STABILIZER VALVE FULLY OPEN

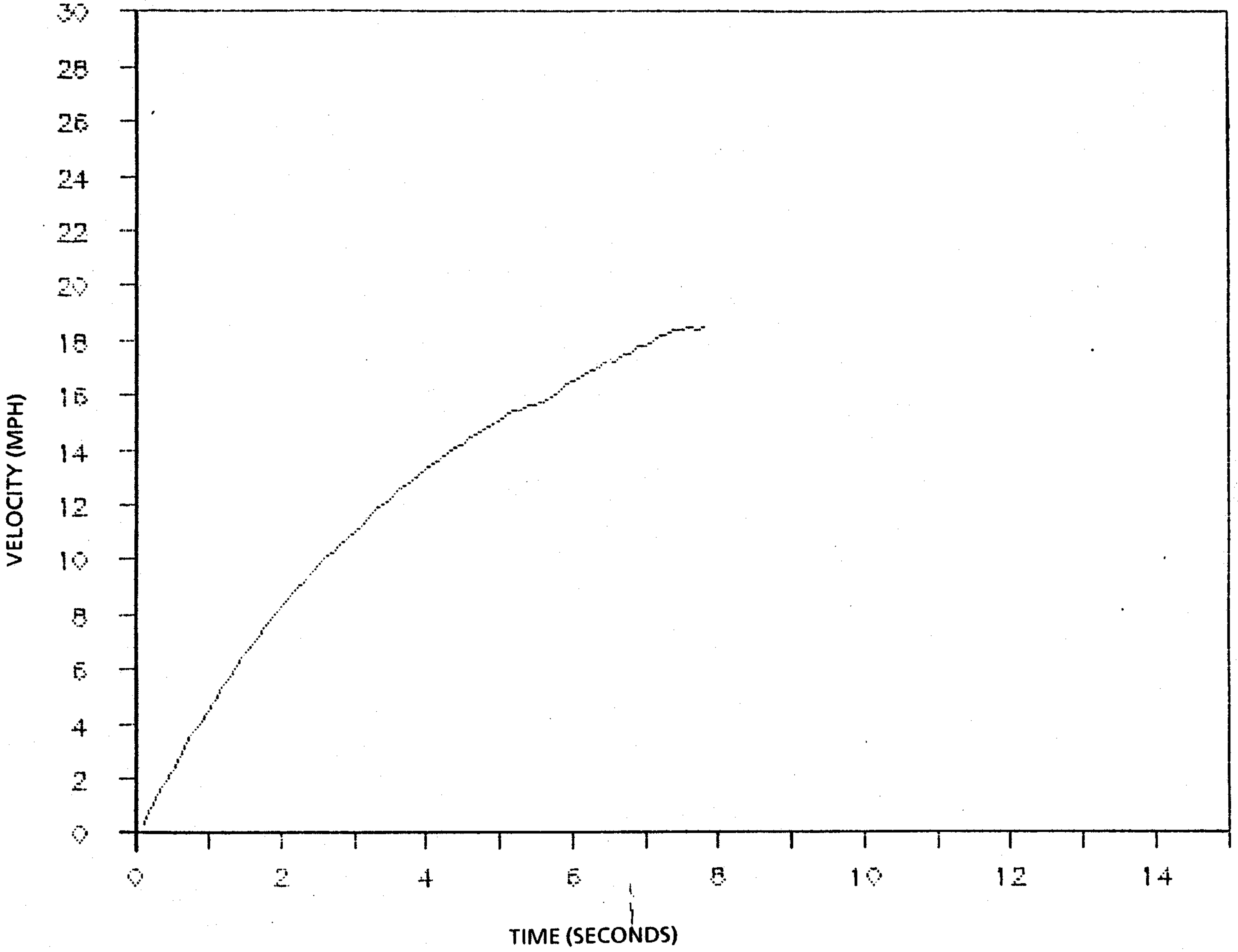


FIGURE B-10. VEHICLE VELOCITY VERSUS TIME, 1986 AUDI 5000S, REVERSE GEAR, IDLE-STABILIZER VALVE FULLY OPEN

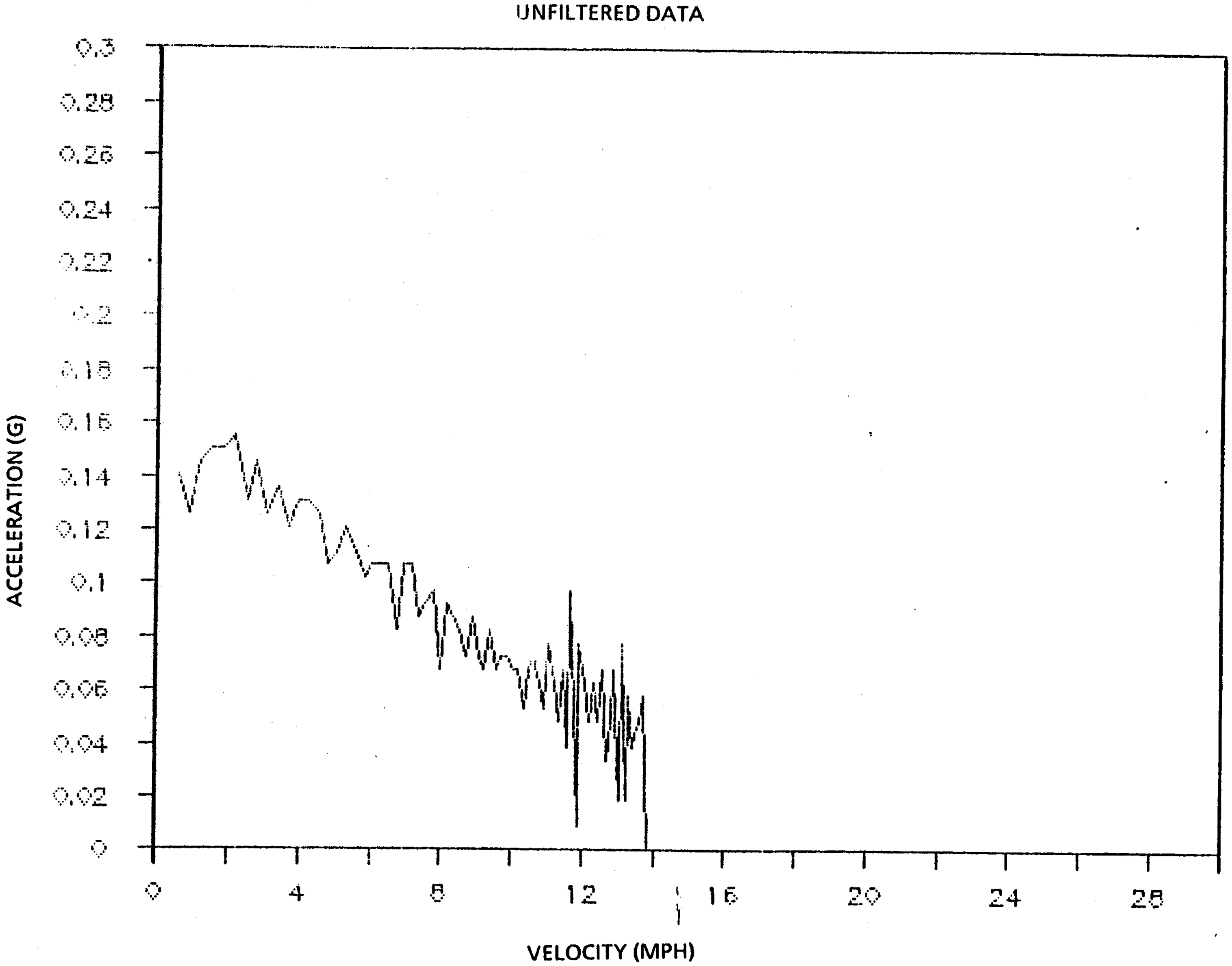


FIGURE B-11. VEHICLE ACCELERATION VERSUS VELOCITY, 1986 AUDI 5000 CS TURBO, REVERSE GEAR, IDLE-STABILIZER VALVE FULLY OPEN

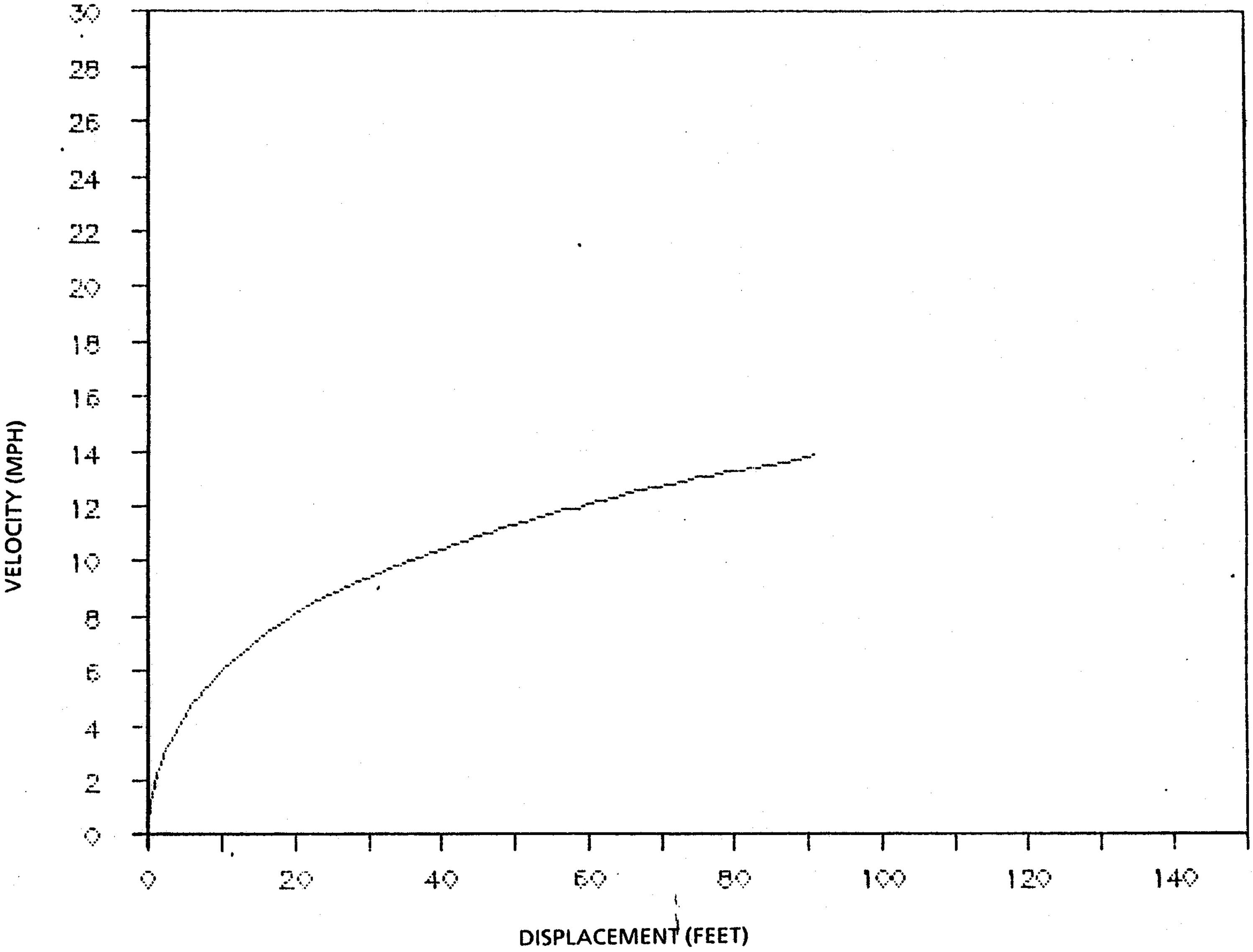


FIGURE B-12. VEHICLE VELOCITY VERSUS DISPLACEMENT, 1986 AUDI 5000 CS TURBO, REVERSE GEAR, IDLE-STABILIZER VALVE FULLY OPEN

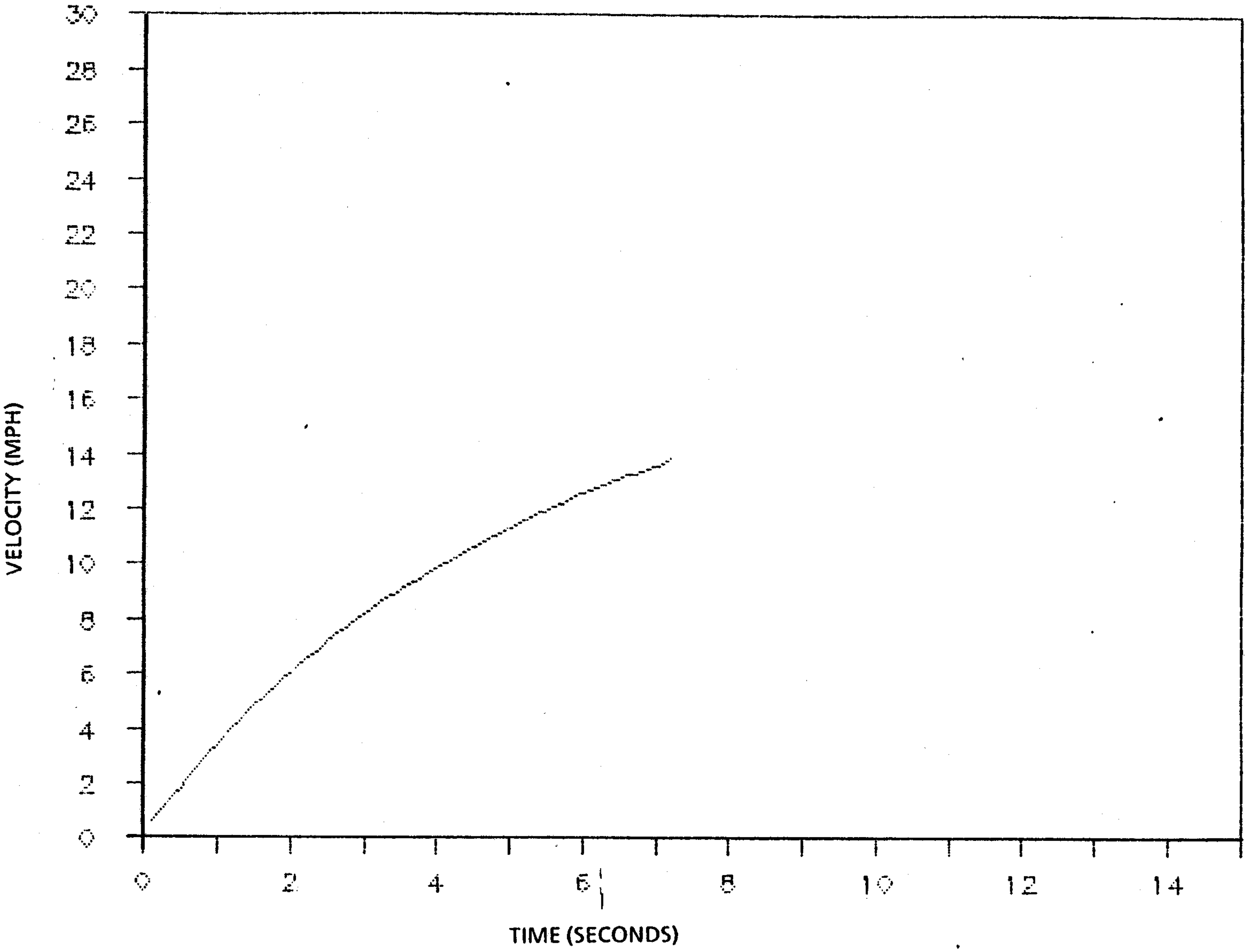


FIGURE B-13. VEHICLE VELOCITY VERSUS TIME, 1986 AUDI 5000 CS TURBO, REVERSE GEAR, IDLE-STABILIZER VALVE FULLY OPEN

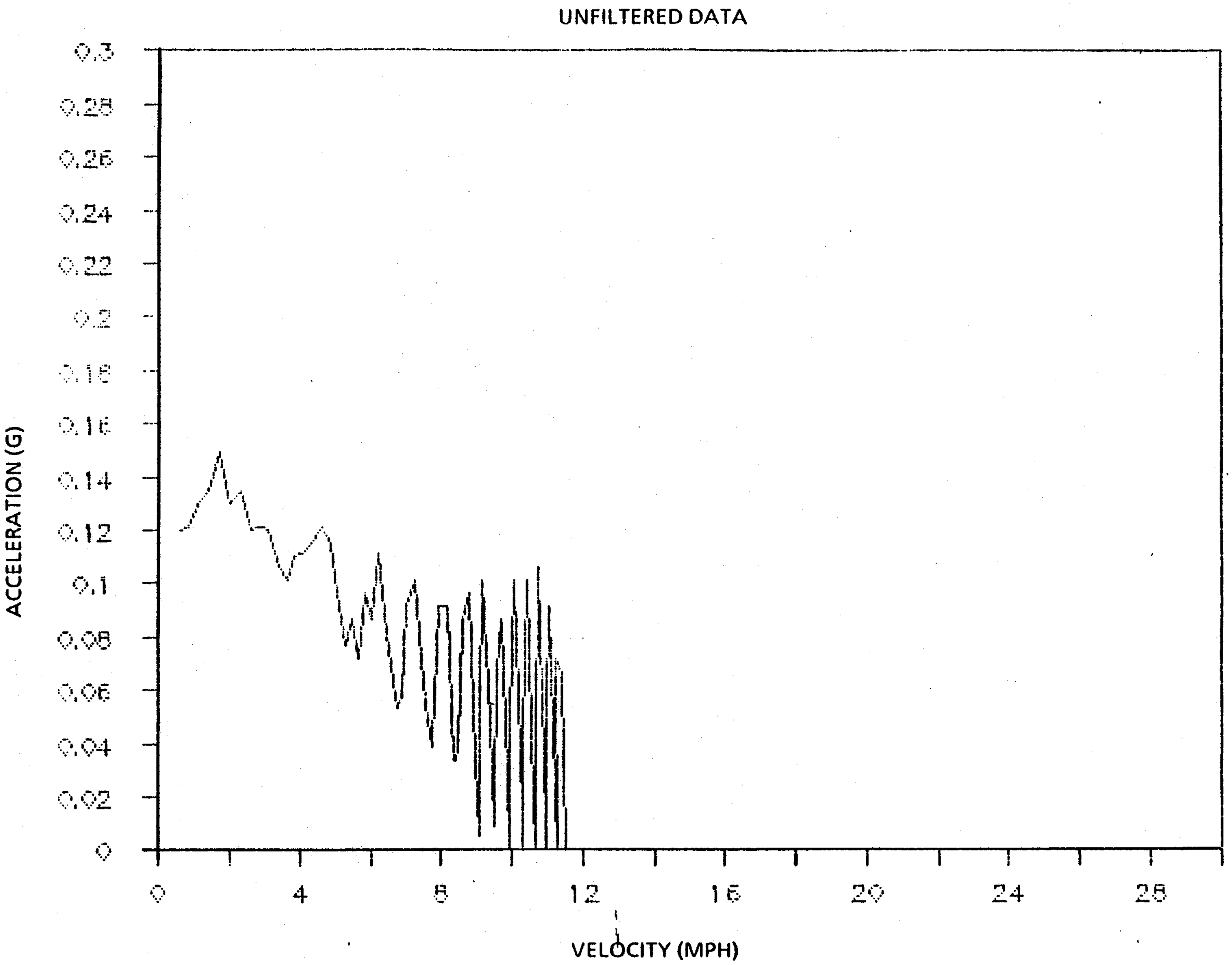


FIGURE B-14. VEHICLE ACCELERATION VERSUS VELOCITY, 1984 AUDI 5000S, REVERSE GEAR, IDLE-STABILIZER VALVE FULLY OPEN

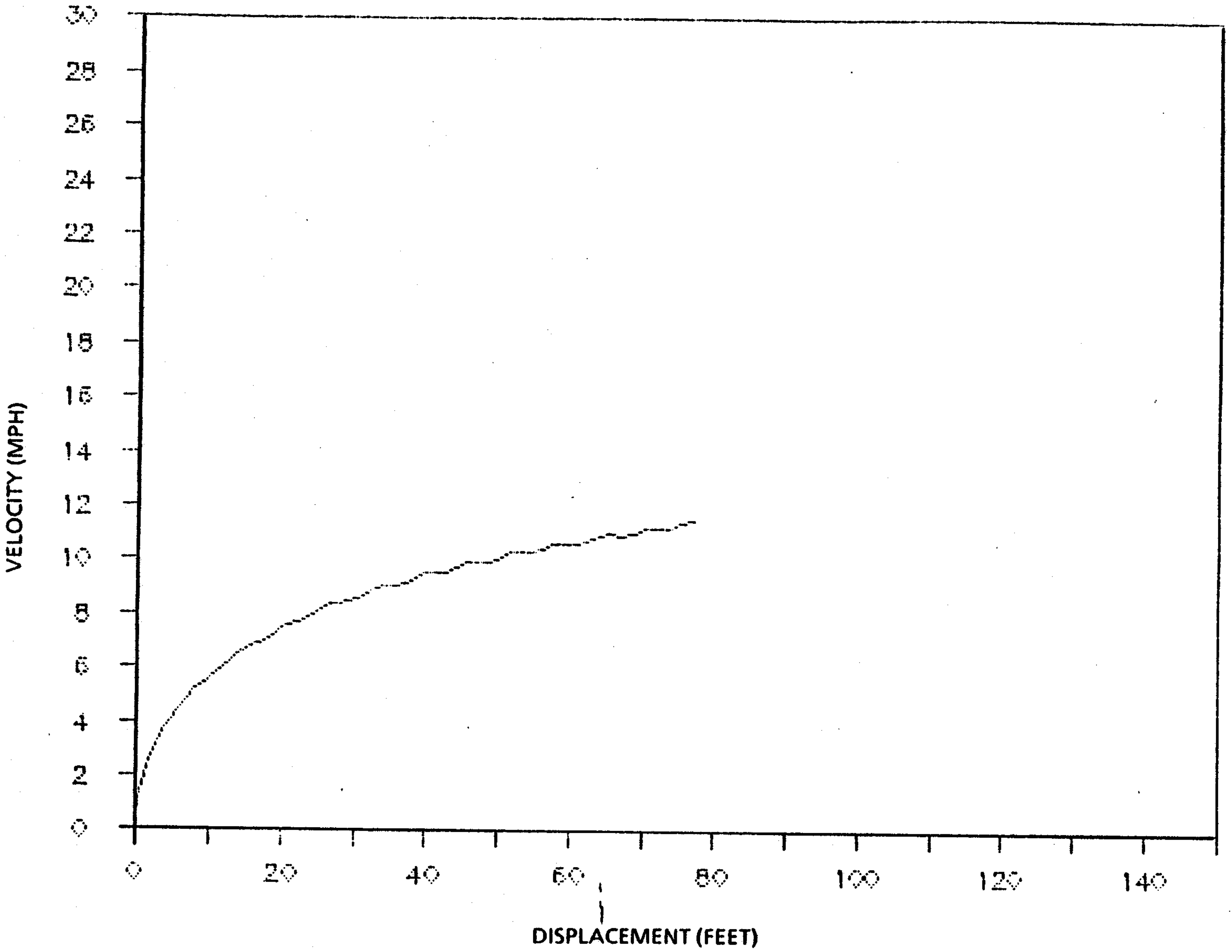


FIGURE B-15. VEHICLE VELOCITY VERSUS DISPLACEMENT, 1984 AUDI 5000S, REVERSE GEAR, IDLE-STABILIZER VALVE FULLY OPEN

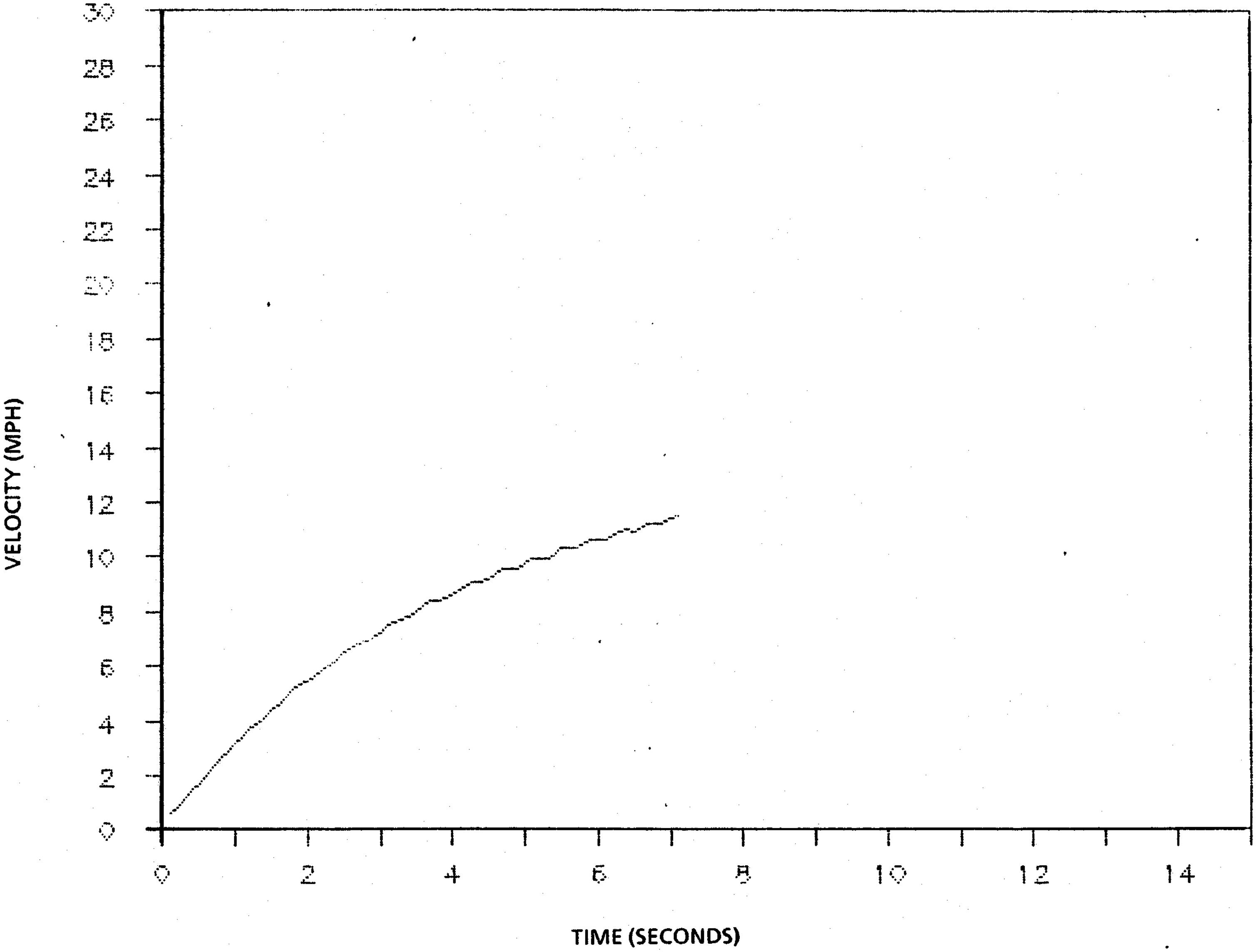


FIGURE B-16. VEHICLE VELOCITY VERSUS TIME, 1984 AUDI 5000S, REVERSE GEAR, IDLE-STABILIZER VALVE FULLY OPEN

APPENDIX C

BRAKE SYSTEM

C.1 INTRODUCTION

After the onset of an SAI, the driver should be able to stop the vehicle by braking. Drivers of Audi 5000s involved in sudden acceleration report that the brake pedal was depressed but the vehicle did not stop. On the assumption that the drivers had properly applied the brakes, the brake system was evaluated to identify any system malfunction which would prevent the driver from stopping the car.

C.2 DESCRIPTION OF THE BOOST SYSTEM COMPONENTS AND THEIR PERFORMANCE

C.2.1. Hydraulic Boost System

The hydraulic boost system, standard on all Audi 5000s built after 1983, is a power-assist mechanism that reduces the force the driver must apply on the brake pedal to stop the car. Located between the brake pedal and the master cylinder, the boost servo is actuated by depressing the brake pedal and deactuated by releasing the brake pedal. With the boost system, the pedal force required to produce .3 g of deceleration (equal to the initial surge caused by a fully open idle stabilizer) is reduced from 90 lb (400 N) to 22.5 lb (100 N), a force reduction of 75 percent (see Figure C-1).

Each time the brake pedal is depressed a high-pressure fluid is delivered to the booster servo. In the event of pumping the brake pedal, a large amount of fluid is required. The hydraulic boost system provides the high-pressure hydraulic fluid as illustrated in Figure C-2.

Hydraulic fluid is pumped by the central pump into a pressure accumulator. A fully charged accumulator stores enough pressurized fluid for about 29 moderate brake applications when the pump is shut off or disabled. The booster servo uses this fluid during braking and then passes it at low pressure to the reservoir. Two pressure-relief valves provide bypass lines directly to the reservoir when pressures exceed allowable levels. When the pump fluid pressure exceeds 155 bars, the pump pressure-relief valve allows fluid to bypass the accumulator and booster servo and return directly to the reservoir. When the accumulator pressure exceeds 150 bars, the accumulator pressure-relief valve allows fluid to bypass the booster servo and return to the reservoir. Fluid in the reservoir is the supply fluid for the pump.

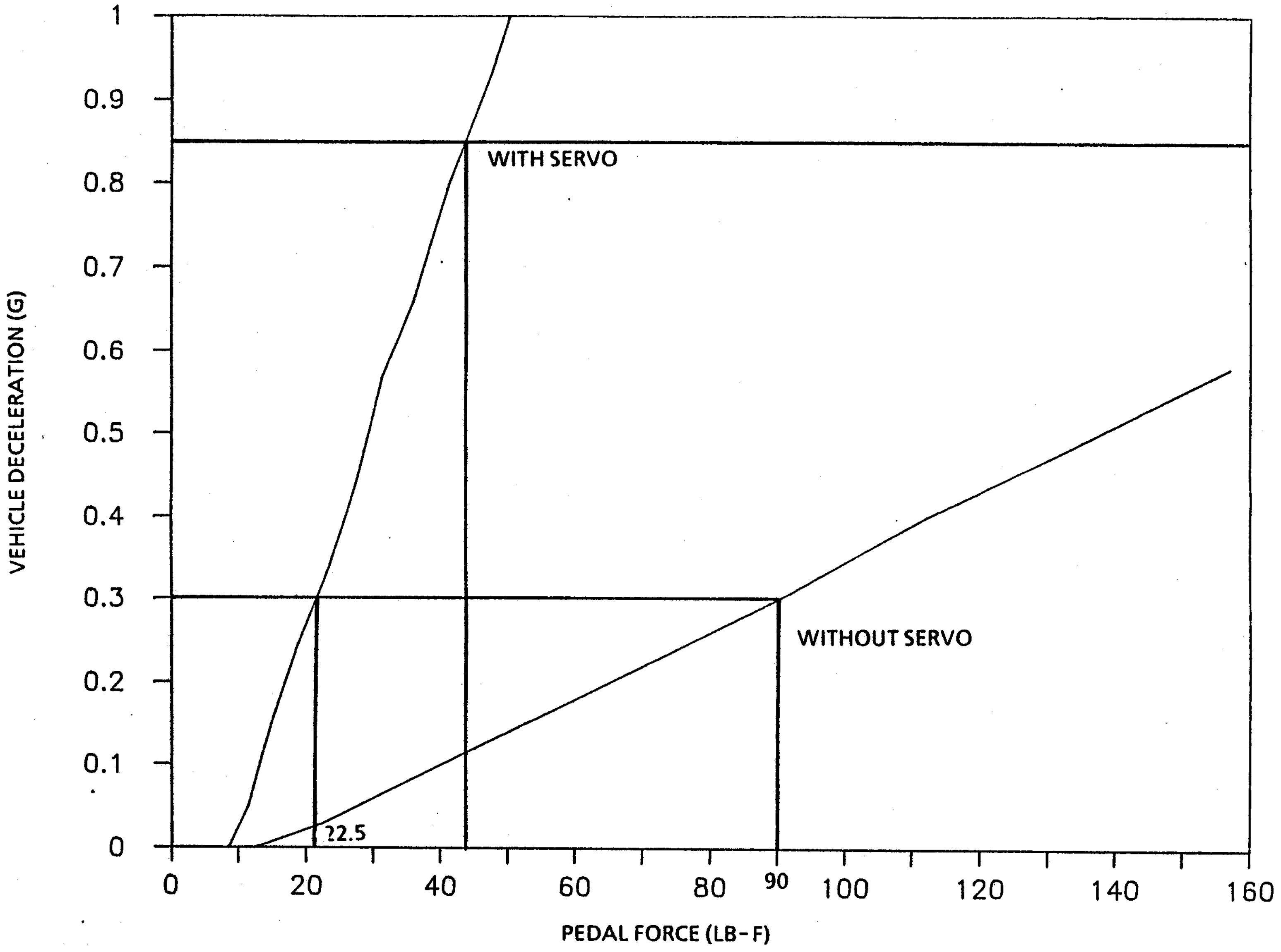
C.2.2 Pump

The continuously operating hydraulic pump is a constant-displacement, eight-piston rotary pump with two independent hydraulic circuits. Six pistons on one circuit supply power steering; two pistons on the second circuit supply fluid for servo braking. The power steering and brake circuits are both supplied with hydraulic fluid from the same fluid reservoir.

The volumetric flow rate from the pump (q) is proportional to engine speed minus losses due to flow past the pump pressure-relief valve or leakages internal to the pump. The flow rate is

$$q = \left(\frac{RPM}{850}\right) q_0 (1 - \alpha P) \qquad [C.1]$$

where 850 represents the engine speed at idle, q_0 is the flow rate from the pump at idle, and α is the volumetric efficiency of the pump. The pump is replaced when the flow rate at idle is below 5 cm^3/sec.



Source: Developed by TSC from VWOA data received through ODI.

FIGURE C-1. BRAKING FORCE REQUIREMENTS

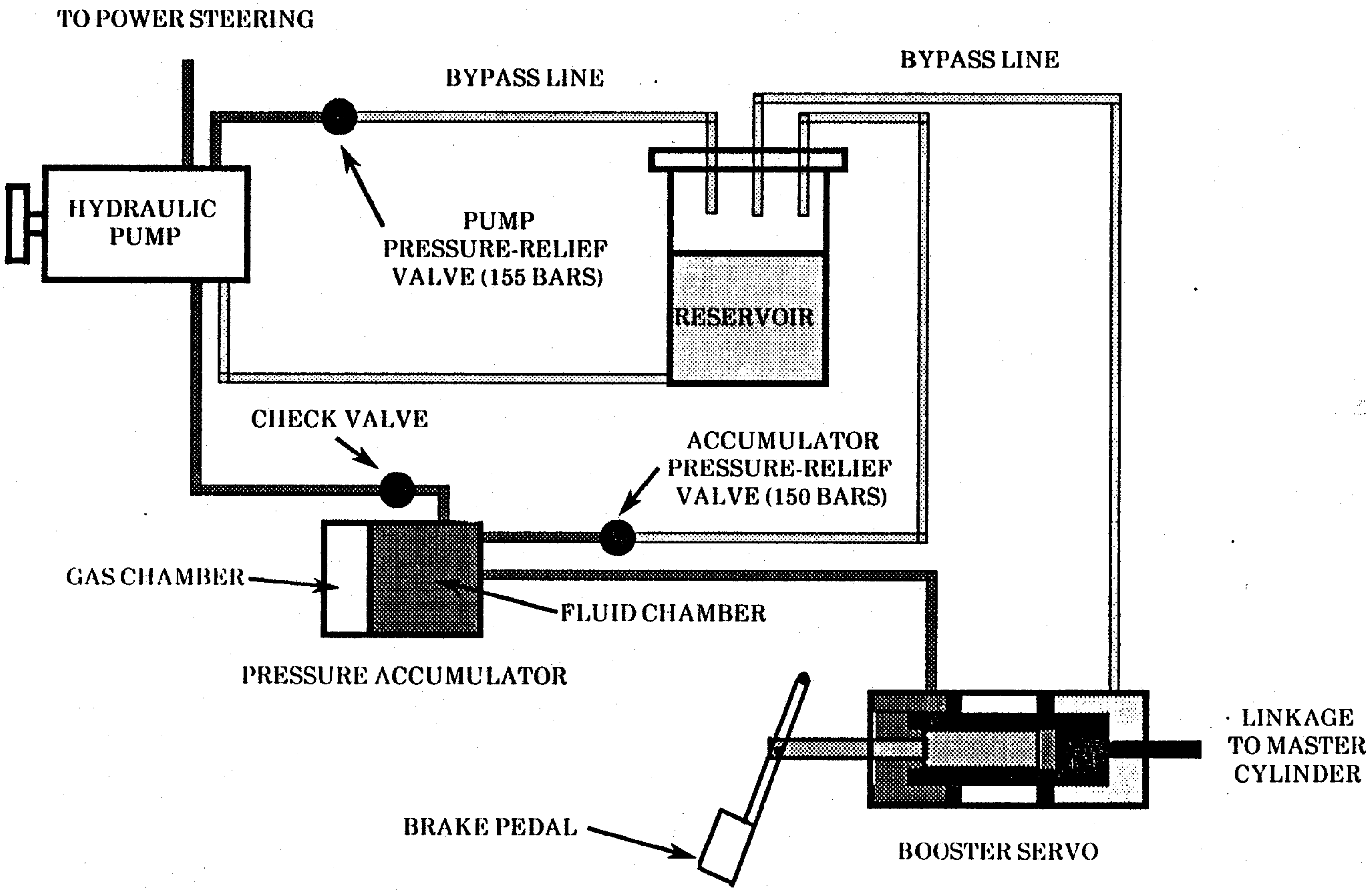


FIGURE C-2. SCHEMATIC OF HYDRAULIC POWER-ASSIST BRAKING SYSTEM

C.2.3 Accumulator

The pressure accumulator is a device that stores hydraulic fluid under pressure to be used by the booster servo. It consists of a rigid shell that encloses a diaphragm which creates two compartments, as illustrated in Figure C-3 (modeled as a moveable piston). One compartment contains a gas at high pressure that is sealed (constant mass). The second compartment is loaded and discharged with hydraulic fluid on an operational basis. Three fluid lines control the loading and discharging of the accumulator. Loading is done through the inlet from the pump; discharging is through the boost servo and pressure-relief valve. Fluid returning back to the pump is prevented by a one-way check valve.

Maximum pressure in the accumulator is limited to the pressure which opens the accumulator pressure-relief valve. The relief valve will open at 150 bars when installed and is replaced when it opens below 140 bars.

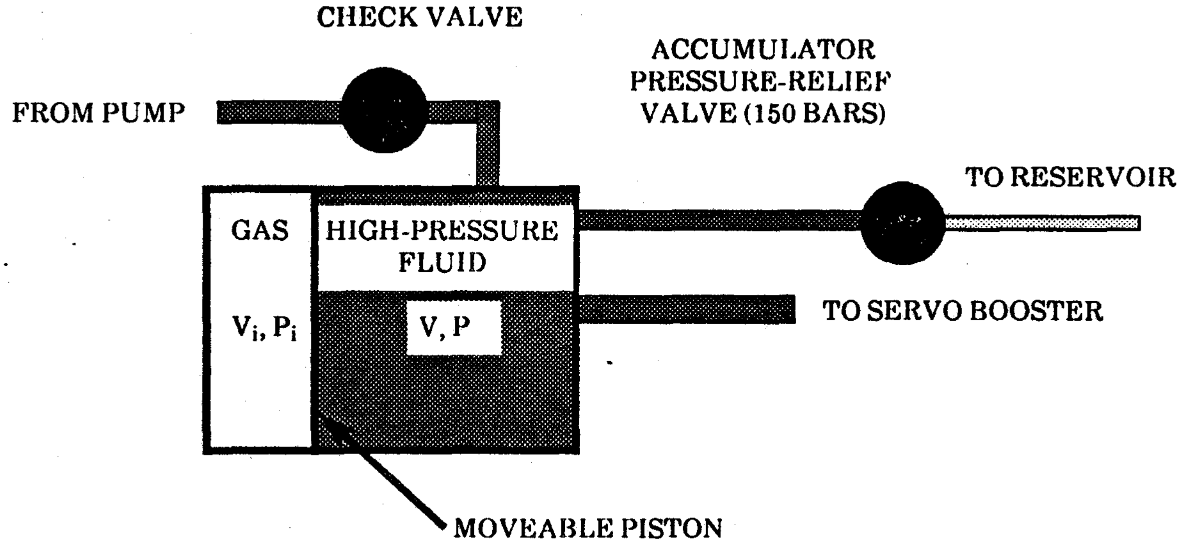


FIGURE C-3. ACCUMULATOR MODEL

Gas pressure varies between the empty pressure (gas pressure when there is no fluid supply in the accumulator) and the full pressure (pressure that opens the relief valve). At installation, the empty gas pressure (P_E) is between 88 and 92 bars. The accumulator is replaced when P_E falls below 30 bars. When the hydraulic fluid pressure is equal to or below the empty pressure, the gas will fill the entire accumulator volume. This volume of gas is the empty volume of the accumulator (V_E). The pump will deliver fluid to the accumulator as long as pressure developed by the pump is greater than the gas pressure in the accumulator. When the gas reaches full pressure (P_F), the relief valve operates continuously until pressure drops below P_F, allowing the hydraulic fluid delivered by the pump to drain into the reservoir.

Gas pressure increases as the fluid volume increases because the trapped gas is being compressed. The diaphragm moves in response to changes in fluid pressure. As fluid pressure increases, the diaphragm compresses the volume of the gas compartment. As the fluid pressure decreases, the volume of the gas expands. The operating gas pressure (above P_E and less the P_F) depends upon the amount of hydraulic fluid in the accumulator, i.e., the difference between the amount of hydraulic fluid being delivered by the pump and the amount of that fluid required by the boost servo during braking. Assuming the gas behaves like an ideal gas, the expression for the expansion or compression of the gas is

$$P_i V_i^n = P_E V_E^n = P_F V_F^n = CONSTANT \qquad [C.2]$$

The exponent represents the thermodynamic process undergone by the ideal gas (air). When $(n = 1)$ the process is isothermal and when $(n = 1.4)$ the process is adiabatic.

The fluid pressure and gas pressure are considered equal in the accumulator. This equation is valid as long as the fluid pressure is greater than the empty gas pressure. The volume of the hydraulic fluid at any pressure in the accumulator is dependent upon the initial pressure and volume of the gas. For example,

$$V_F = \left(\frac{P_E}{P_F}\right)^n V_E \qquad [C.3]$$

<u>Accumulator Discharge</u> - Loss of fluid in the accumulator is proportional to the number of pedal depressions (N) and the volume of fluid displaced per pedal depression (Δ). The volume of gas in the accumulator during discharging can be expressed as

$$V_i = (V_F + N\Delta) \qquad [C.4]$$

The amount of fluid removed from the accumulator per pedal depression is equal to the volume of fluid entering the assist chamber in the servo unit and is proportional to the pedal displacement. For example, a pedal displacement of 33 mm removes 4.5 cm^3 of fluid from the accumulator and produces 20 bars of brake pressure.

Combining equations C.1 and C.2, the pressure during bleed-down (P_B) in the accumulator is

$$P_B = \frac{P_F}{\left(1 + \frac{N\Delta}{V_F}\right)^n} \qquad [C.5]$$

Test data provided by VWOA show the relationship between gas pressure versus the number of 20-bar brake applications. For the test performed, the initial gas pressure was 140 bars; the brake was applied 36 times before the accumulator was emptied. The volume of the accumulator at 140 bars (V_F) is

$$\frac{V_F}{\Delta} = \frac{N}{\frac{P_F}{P} - 1} \qquad [C.6]$$

assuming $n = 1$, and substituting values of N and P into equation C.6. V_F/Δ is then substituted into equation C.3 and the bleed-down curve is developed and compared to the test data. When $N = 29$, $P = 78$; $V_F/\Delta = 36.5$ ($V_F = 164.2$ cm3), the best approximation of the bleed-down curve is achieved. (See Figure C-4.)

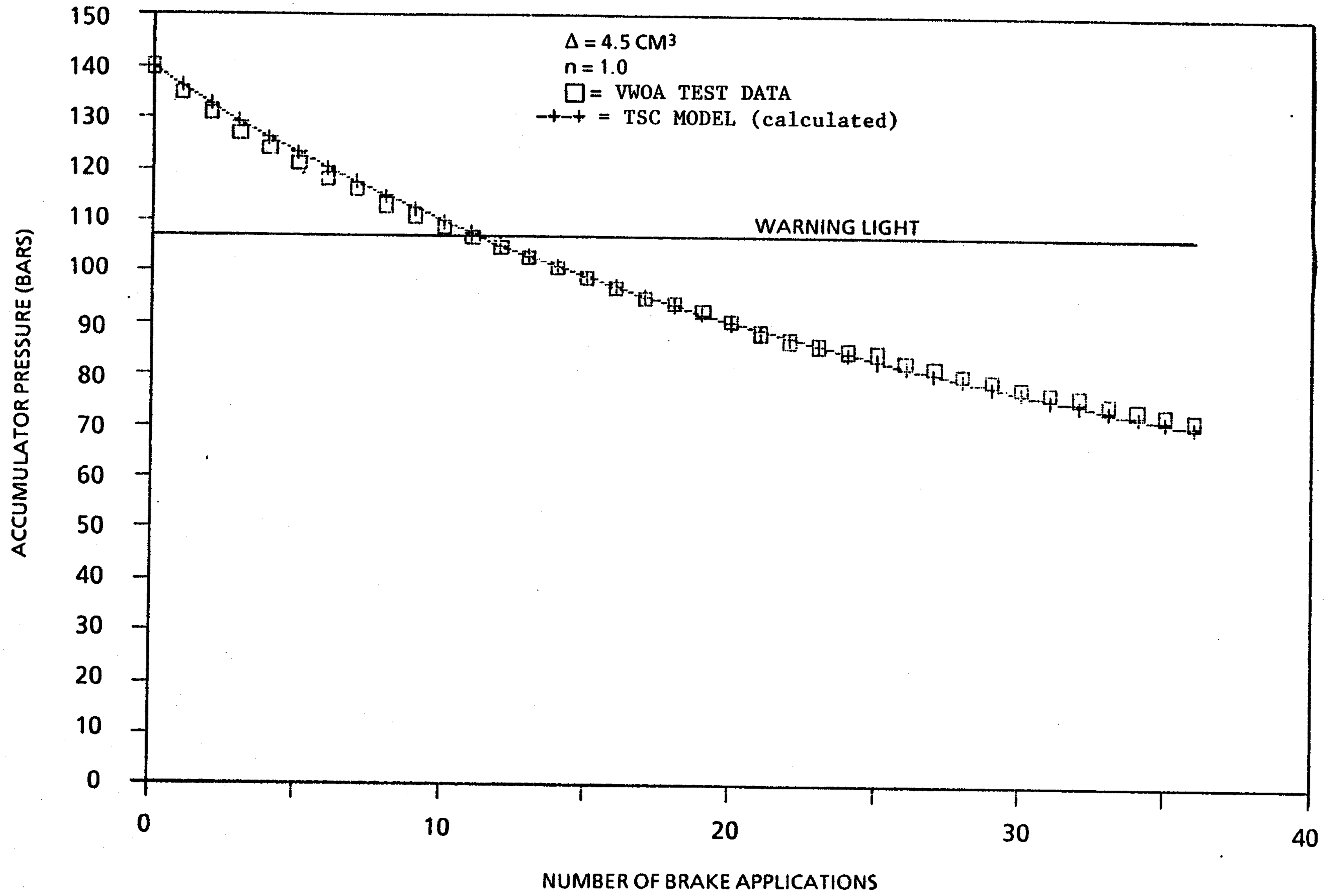


FIGURE C-4. BLEED-DOWN CURVE

For the curve shown n = 1, indicating the bleed-down process can be considered an isothermal expansion of an ideal gas, and the assumption to determine the volume of gas in the accumulator is justified. The parameter $\Delta = 4.5$ cm^3, the volume of fluid associated with producing a brake line pressure of 20 bars if the empty accumulator pressure is 72 bars. The volume of the gas in an empty accumulator was then determined from equation C.2. Given the initial pressure (140 bars), which is the initial volume (164.4 cm^3) and the empty pressure (72 bars), for n = 1 the empty volume of the accumulator is 320 cm^3.

<u>Loading of the Accumulator</u> – Loading time of the accumulator is defined as the amount of time required to raise the pressure of the gas in the accumulator from the empty pressure to any specified pressure (see Figure C-5). The empty pressure is the gas pressure when there is no hydraulic fluid present in the accumulator. This pressure can range between 92 and 30 bars.

The loading time of the accumulator at idle speed is proportional to the volumetric flow rate of fluid (q) past the check valve from the pump. The volume of gas at any time during loading is

$$V_i = (V_E - qt) \qquad [C.7]$$

Combining equation C.7 and equation C.2, the pressure during loading (P_L) in the accumulator is

$$P_l = \frac{P_E}{\left(1 - \frac{qt}{V_E}\right)^n} \qquad [C.8]$$

Test data supplied by VWOA show the relationship between gas pressure versus time during loading of the accumulator from empty pressures of 30 and 80 bars. In this instance, it took 19 seconds to load the accumulator from 80 to 144 bars, and 36 seconds to load it from 30 to 144 bars.

If the parameters in equation C.8 are constant, the ratio of the 80-to30-bar loading curve would then also be constant; the test data indicate, however, that this is not the case. The volumetric efficiency of the pump was assumed as (1-αP) to account for internal pump leakage losses due to pressure.

The flow rate into the accumulator at idle speed is

$$q = q_o(1 - \alpha P) \qquad [C.9]$$

The parameters n, q_0, and α were varied to achieve the best approximation of the loading curve data (see Figure C-5). For the two curves shown: n = 1.4, q_0 = 8.5 cm^3/sec, and α = 0.0023 bar^{-1}.

The volumetric flow rate from the pump (q) is proportional to engine speed minus losses due to flow past the pump pressure-relief valve or leakages internal to the pump. The general expression for the flow rate to the accumulator becomes:

$$q = \left(\frac{RPM}{850}\right) q_o(1 - \alpha P) \qquad [C.10]$$

where 850 is the idle speed of the engine and (1-αP) is the volumetric efficiency term.

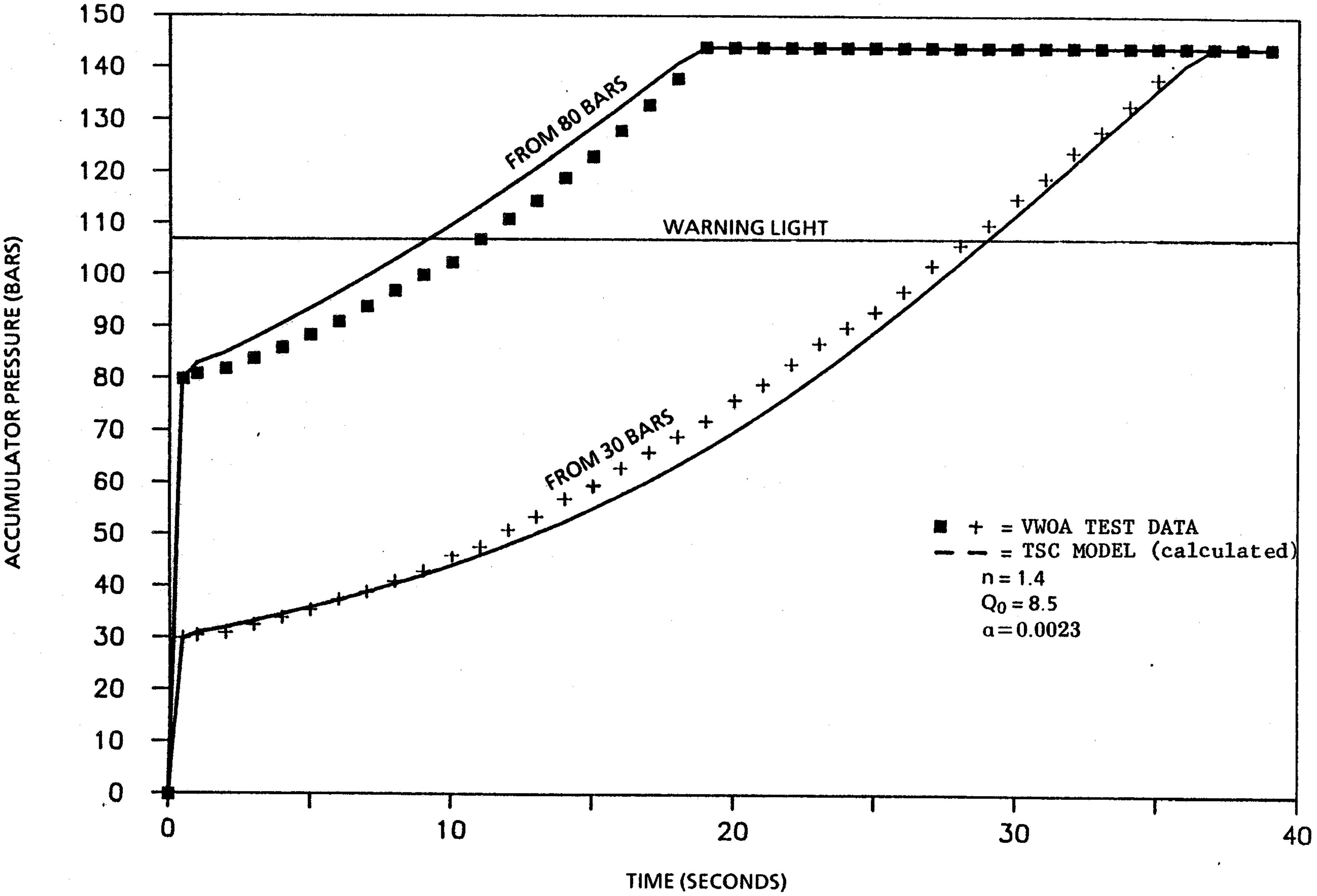


FIGURE C-5. LOADING TIME FOR BRAKE ACCUMULATOR

C.3 THE HYDRAULIC BRAKE ASSIST

Using the high-pressure fluid provided by the accumulator and pump, the boost servo reduces the pedal force required of the driver to brake the car. The hydraulic boost servo is located between the brake pedal and the master cylinder. The three primary components of the boost servo are the boost piston, the spool valve, and the housing. Figure C-6 is a schematic of the boost servo components in their relative locations in the relaxed position. The boost piston is connected to the master cylinder piston so that both pistons have the same relative displacements. The brake pressure developed by the master cylinder is therefore proportional to boost piston displacement.

The power assist is activated when the pedal is depressed by displacing the spool valve. The return spring (located between the piston and the spool valve) deactivates the servo when the pedal is released. The high- and low-pressure ports can be opened or closed depending upon the relative position between the piston and spool valve, but cannot be opened at the same time. The piston and spool valve are cylindrical in shape. Piston seals separate the regions between the piston and the housing into three fluid chambers. These are the power-assist chamber, the fluid supply chamber, and the fluid return chamber. The power-assist chamber is between the housing on the brake-pedal side where the spool valve passes through and the piston seal on the brake-pedal side of the high-pressure port. The supply chamber is between the two piston seals. The return chamber is between the piston seal on the master cylinder side of the high-pressure port and the housing on the master cylinder side where the piston shaft passes through, as shown in Figure C-6. Selected dimensions of the boost piston and spool valve are given in Figure C-7.

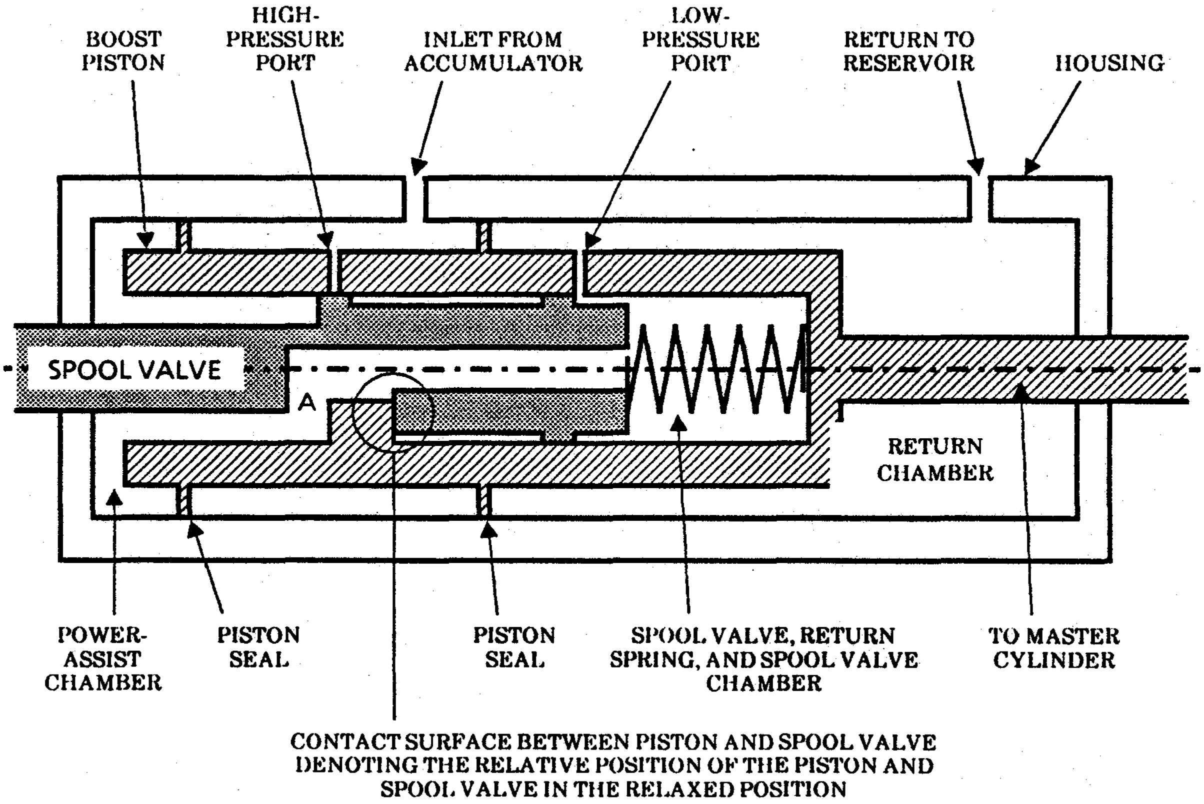
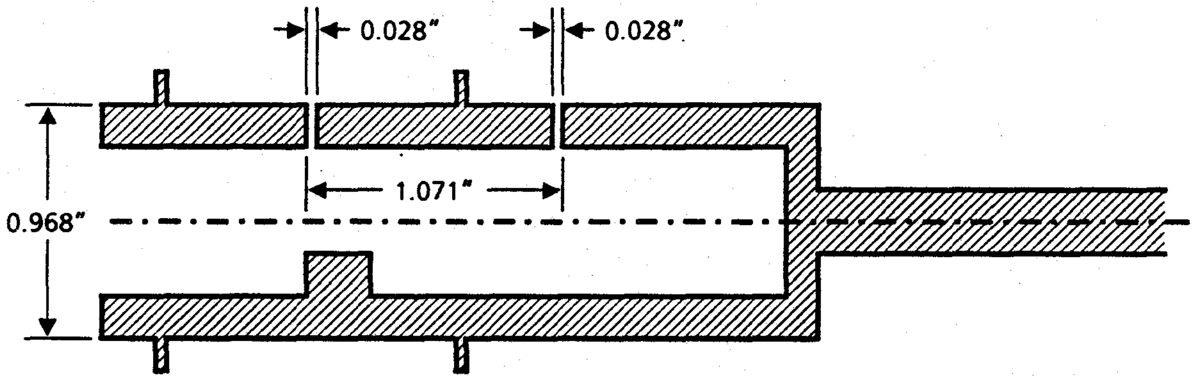
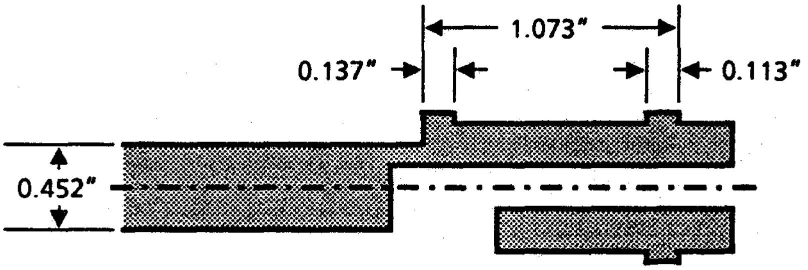


FIGURE C-6. HYDRAULIC BRAKE-ASSIST SERVO IN RELAXED POSITION



PISTON



SPOOL VALVE

FIGURE C-7. SELECTED DIMENSIONS OF THE PISTON AND SPOOL VALVE

C.3.1 Boost Servo Operation

Before braking, the components of the servo sit in the relaxed position shown in Figure C-6. In this position, the high-pressure port is closed and the low-pressure port is open. The power-assist chamber, the spool valve chamber, and the return chamber are open to each other, through passageway A and the low-pressure port. The three chambers are open to the reservoir through the return line so the pressure in the chambers is equal to atmospheric pressure. Because no pedal force is being applied, the servo is not activated and there is no vehicle braking. The master cylinder piston is displaced as far toward the brake pedal as possible, causing no brake line pressure.

C.4 NORMAL OPERATION

C.4.1 Applying the Brakes

As the driver depresses the brake pedal, the spool valve is initially displaced within the piston, with a force F_S. F_S is proportional to the pedal force the driver applies, but is not equal to it because of the linkages between the pedal and the spool valve. As shown in Figure C-8, when the spool valve is initially displaced the high-pressure port is opened and the low-pressure port is closed.

When the low-pressure port closes, the power-assist chamber and spool valve chamber are sealed from the return chamber. High-pressure fluid from the accumulator flows into the power-assist and spool valve chambers. Since no fluid can pass the closed low-pressure port, the volume of fluid that passes

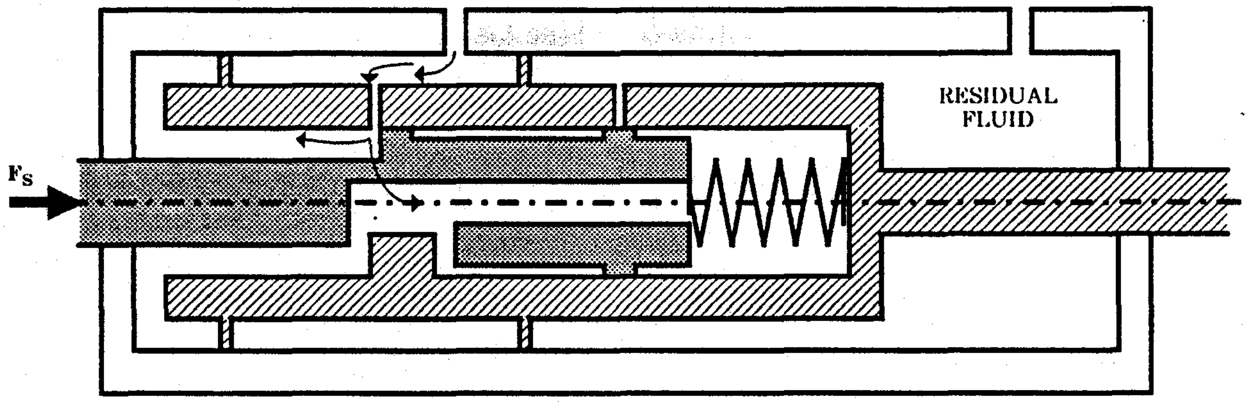


FIGURE C-8. SPOOL VALVE DISPLACEMENT

the high-pressure port is equal to the volume increase of the spool valve and power-assist chambers. Assuming a great enough fluid pressure, the high-pressure fluid forces the boost piston toward the master cylinder, which displaces the master cylinder piston and causes brake line pressure to increase. The spool valve displaces toward the master cylinder at a slower rate than the boost piston. Relative to the boost piston, the spool valve is displaced toward the relaxed position, as shown in Figure C-9. Note that as the boost piston displaces toward the master cylinder, residual fluid in the return chamber is forced back to the reservoir.

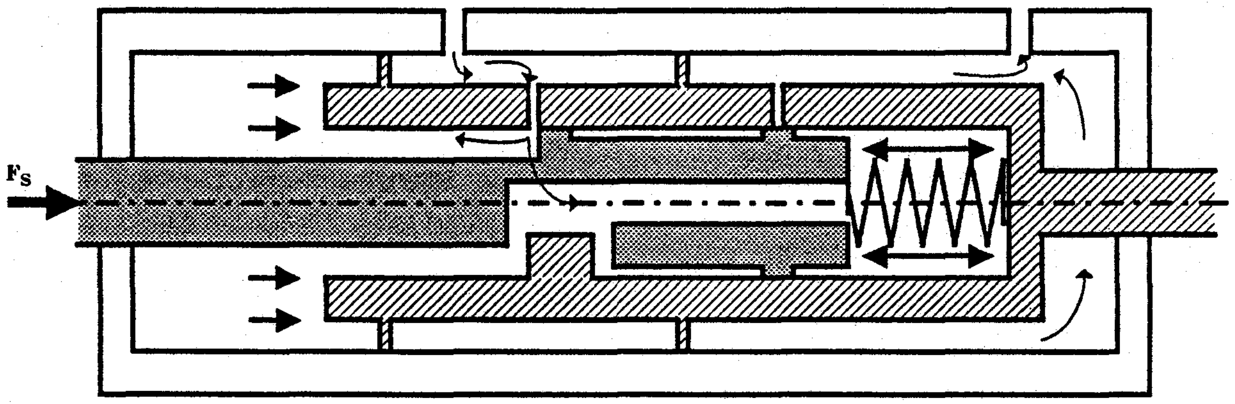


FIGURE C-9. SPOOL VALVE DURING BRAKE RELEASE

Increasing fluid pressure in the assist and spool valve chambers as the piston displaces toward the master cylinder provides the force required to increase the brake line pressure. The fluid pressure acting on the spool valve cross-sectional area provides increasing resistance to the applied pedal force. Because the piston has displaced toward the master cylinder further than the spool valve, the high-pressure port opens slightly. This relative position of the spool valve and piston occurs only when pressure force on the spool valve in the spool valve chamber (F_{SV}) is slightly less than the applied spool valve force (F_S). If the pressure was much less, F_S would have little resistance to displacement within the piston and would allow the high-pressure port to remain fully opened. Similarly, if the pressure force F_{sv},were much greater, it would overcome F_s, close the high-pressure port, and open the low-pressure port.

The pressure force in the spool valve chamber increases to equal the applied force to the spool valve (pedal force through linkage), stopping pedal displacement. The increased pressure in the assist chamber displaces the boost piston toward the master cylinder, increasing the brake pressure and closing the high-pressure port. When the high-pressure port closes, the flow into the assist and spool valve chambers is stopped; the forces are balanced and the boost piston no longer moves, as shown in Figure C-10. The applied spool valve force is balanced by the pressure force in the spool valve chamber. The low-pressure port remains closed because the piston displacement stops when the high-pressure port closes. The spool valve will not return to the relaxed position until the brake pedal is released; the applied force is reduced below the pressure force in the spool valve chamber. No fluid enters or leaves the assist and spool valve chambers, and neither the boost piston nor the spool valve moves (the system is in force equilibrium). Figure C-11 shows the forces acting on the piston and spool valve in the equilibrium position.

Because the assist and spool valve chambers are connected through passageway A, their fluid pressures (P_f) are equal. In the equilibrium position, the applied force through the spool valve is equal to the spool valve pressure force in the spool valve chamber, excluding the return spring force. The spool valve force is

$$F_s = F_{sv} = P_f A_s \qquad [C.11]$$

where A_s is the cross-sectional area of the spool valve normal to the centerline. The spool valve pressure force (F_{sv}) plus the assist chamber pressure force (F_a) is the boost force (F_b) which produces brake pressure in the master cylinder. The boost force is

$$F_b = F_a + F_{sv} = P_f(A_a + A_s) \qquad [C.12]$$

where A_a is the cross-sectional area of the assist chamber. The area of the assist chamber on which the fluid works is the cross-sectional area of the piston (A_t) minus the cross-sectional area of the spool valve (A_s). From the dimensions given in Figure C-7, the area of the assist chamber (A_a) is

$$A_a = A_t - A_s = \frac{\pi}{4}\left(0.968^2 - 0.452^2\right) = 0.575\ in^2 \qquad [C.13]$$

Since $A_a + A_s$ is the cross-sectional area of the piston, A_t, the boost force is

$$F_b = P_f A_t \qquad [C.14]$$

The purpose of the boost is to reduce the applied pedal force required to brake the car. Since brake pressure is proportional to the boost force (F_b) and the spool valve force (F_s) is proportional to the applied pedal force, the boost servo reduces required pedal force only if F_b is greater than F_s. Combining equations C.11 and C.14, the boost force as a function of applied spool valve force is

$$F_b = \frac{A_t}{A_s} F_s \qquad [C.15]$$

The servo booster multiplies the input force by the ratio of the spool valve cross-sectional area to the piston cross-sectional area. From the dimensions given in Figure C-7,

$$F_b = \frac{A_t}{A_s} F_s = \left(\frac{.968}{.452}\right)^2 F_s = 4.59 F_s \qquad [C.16]$$

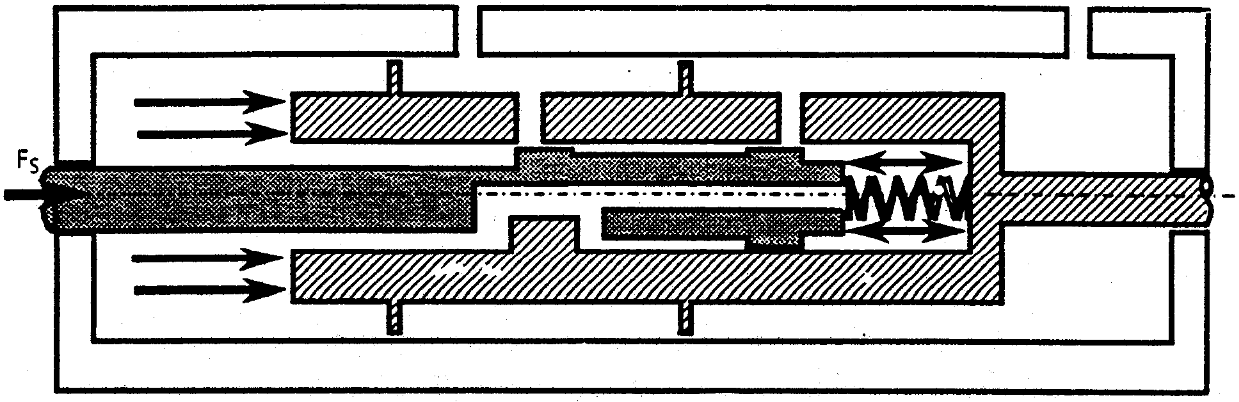


FIGURE C-10. CLOSED HIGH-PRESSURE PORT

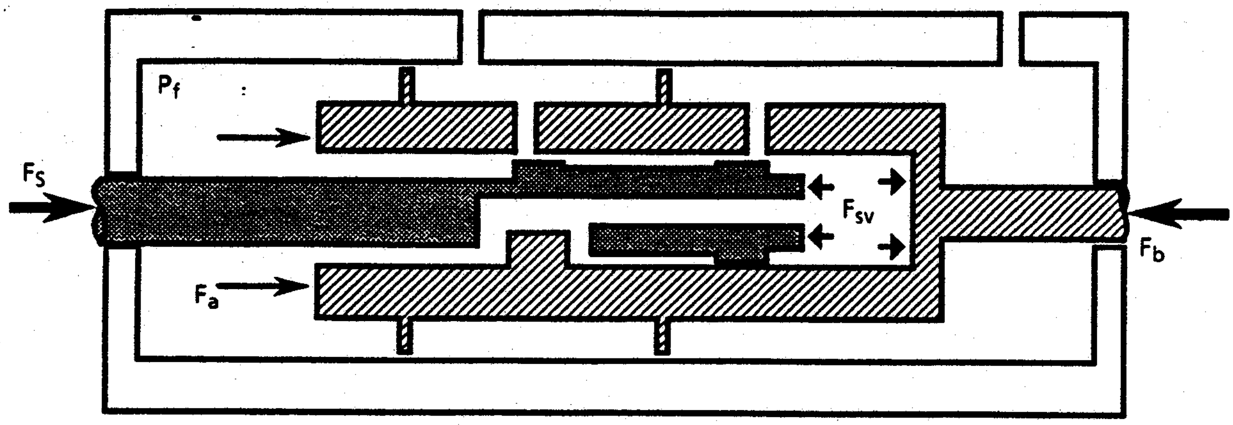


FIGURE C-11. BOOST SERVO COMPONENTS IN EQUILIBRIUM POSITION

The boost force will be 4.59 times the input force for normal operation of the boost servo. The system will remain in equilibrium as long as F_s remains constant. If F_s increases by ΔF_s, the spool valve is displaced toward the master cylinder, which opens the high-pressure port. Fluid then flows into the spool valve and assist chambers, increasing the fluid pressure. As pressure is gained, the force F_{sv} will increase to the applied force $F_s + \Delta F_s$, and stop spool valve displacement. The piston displaces toward the master cylinder, which closes the high-pressure port and increases boost force to $F_b + 4.59\Delta F_s$ at the new equilibrium. Similarly, if the driver decreases F_s by ΔF_s, the spool valve is displaced toward the brake pedal, and opens the low-pressure port. As fluid flows from the spool valve and assist chambers into the return chamber, fluid pressure decreases. As pressure is lost, the pressure force F_{sv} decreases to the applied force F_s-ΔF_s. The piston displaces toward the brake pedal, decreases boost force to F_b-$4.59\Delta F_s$, and closes the low-pressure port at the new equilibrium.

C.4.2 Releasing the Pedal

When the brake pedal is released, the applied force becomes zero. As shown in Figure C-12, the pressure force in the spool valve chamber (F_{sv}) pushes the spool valve back to the relaxed position relative to the piston, and the return spring holds the spool valve in this relaxed position. The assist and spool valve chambers open to the return chamber through the low-pressure port while the high-pressure port remains closed. Fluid at high pressure in the assist and spool valve chambers flows into the return chamber and lowers the fluid pressure. The brake pressure that was developed displaces the piston back toward the brake pedal and forces more fluid into the return chamber. Eventually, the assembly returns to the relaxed position shown in Figure C-6.

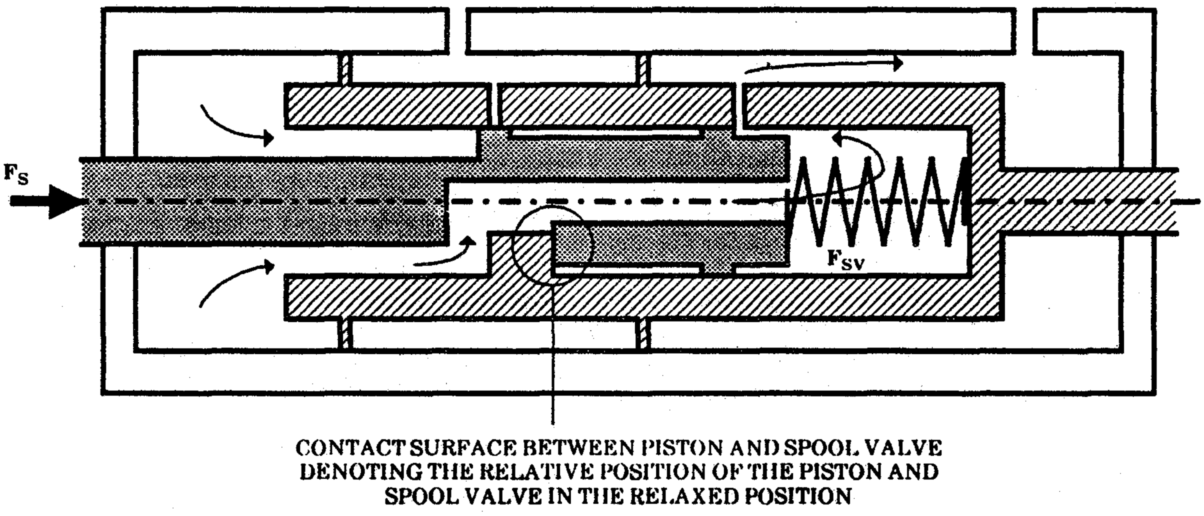


FIGURE C-12. SPOOL VALVE, RELAXED POSITION (FOOT OFF PEDAL)

C.5 FAILURE OF THE BOOST SERVO

Failure of the boost servo can occur when the equilibrium fluid pressure is equal to the supply pressure, thus preventing pressure in the servo from increasing. For example, an applied force increase from F_s to $F_s + \Delta F_s$ displaces the spool valve within the piston and opens the high-pressure port. Since no potential exists across the port (because the fluid pressures are equal), no fluid enters the assist and spool valve chambers, the pressure in the servo does not increase, and no additional fluid boost is created by increasing the applied force. The increase in the applied force (ΔF_s) that displaced the spool valve transmits from the spool valve to the piston by direct contact. The spool valve displaces full stroke within the piston due to ΔF_s because the F_{sv} cannot increase by ΔF_s to stop its displacement. At full stroke the piston and spool valve are in contact at a surface in the spool valve chamber. Since the additional force is transmitted directly to the piston, the additional force developed by the boost servo is equal to the additional force, ΔF_s. The piston displaces toward the master cylinder due to the increase in force, which increases brake pressure. The increase in brake pressure in the failure mode is proportional to F_s, not $4.59\Delta F_s$ as was the case in normal operation. A failure would occur if the fluid pressure force in the spool valve chamber, F_{sv}, was maximum before the applied force increased. When the applied force increases, F_{sv} cannot increase because fluid pressure does not increase. When F_s is greater than F_{sv}, $F_s > P_f A_s$ the boost servo cannot provide fluid boost. At or above the failure level of applied force, an increase in force raises the boost force by an amount equal to the increase in applied force. Since brake pressure increases in proportion to an increase in boost force, the increase is proportional to ΔF_s, whereas the increase in brake pressure during normal operation ($F_s < F_{sv}$) is proportional to $4.59\Delta F_s$.

The boost servo provides boost assist until the fluid pressure in the servo reaches the supply pressure. The boost force is 4.59 times the applied force. The maximum spool valve pressure force, $F_{sv_{max}}$, is the spool valve pressure force when the fluid pressure in the servo is equal to the supply pressure. In equilibrium at $F_{sv_{max}}$, the servo provides the maximum boost-assisted boost force of $4.59F_{sv_{max}}$, the maximum boost-assisted brake pressure. As long as the pressure in the servo remains at the supply pressure, the boost servo will produce at least $4.59F_{sv_{max}}$. Any applied force greater than $F_{sv_{max}}$ will be produced by an additional boost force of $F_s - F_{sv_{max}}$. The total boost force in the failure mode is $4.59F_{sv_{max}} + (F_s - F_{sv_{max}})$.

The fluid supply pressure can be between atmospheric pressure and 150 bars during normal boost servo operation. Therefore, failure of the boost servo occurs at different applied force levels depending upon the supply pressure. When the supply pressure is atmospheric pressure, there is no boost assist, and the boost-assisted brake pressure is zero. The driver must apply the entire force required to achieve any brake pressure when there is no supply pressure. Based on the data supplied by VWOA, the boost servo will provide boost-assisted brake pressure up to 150 bars when the supply pressure is 140 bars. A brake pressure of 150 bar corresponds to 0.85 g of deceleration. Figure C-13 shows the relationship between vehicle deceleration and pedal force for supply pressures of 140, 120, 100, 80, 60, and 30 bars and without servo (atmospheric pressure). This figure also illustrates the change in behavior of the braking system due to a servo-assist failure. Before the failure, vehicle deceleration increases rapidly as a function of pedal force. At the failure pressure, the curve is discontinuous; the servo cannot supply additional fluid boost. Increasing the pedal force from the failure pressure, the brake pressure increases at a rate approximately 6 times less than the prefailure rate.

C.5.1 Behavior of the Brake Pressure With and Without the Servo Booster

The shaft from the boost piston in the servo assist is connected to the piston in the master cylinder. Therefore, the brake pressure is directly proportional to the boost force (see Figure C-14). Test data supplied by VWOA (see Appendix B) show that the brake pressure is linearly proportional to pedal force with or without servo assist. Brake pressure can be developed with or without the servo booster. The servo assist allows the driver to achieve 30 bars of brake pressure with 22.5 lb (100 N) of pedal force. Without the assist, 90 lb (400 N) of pedal force is required to achieve the same brake pressure. The upper limit of servo operation corresponding to a pedal force of 72 lb (310 N) and an accumulator pressure of 140 bars is 150 bars of brake pressure. The brake pressure increases from 150 bars at the same rate as the "without servo" curve. The servo assist will multiply the pedal force by 4.59 if the pedal force is less than the pressure force in the spool valve chamber. Once the pedal force becomes greater than the spool valve pressure force, the servo force will increase equally with pedal force. Brake pressure is proportional to the servo force by a constant of proportionality, expressed as $P_b k F_b$.

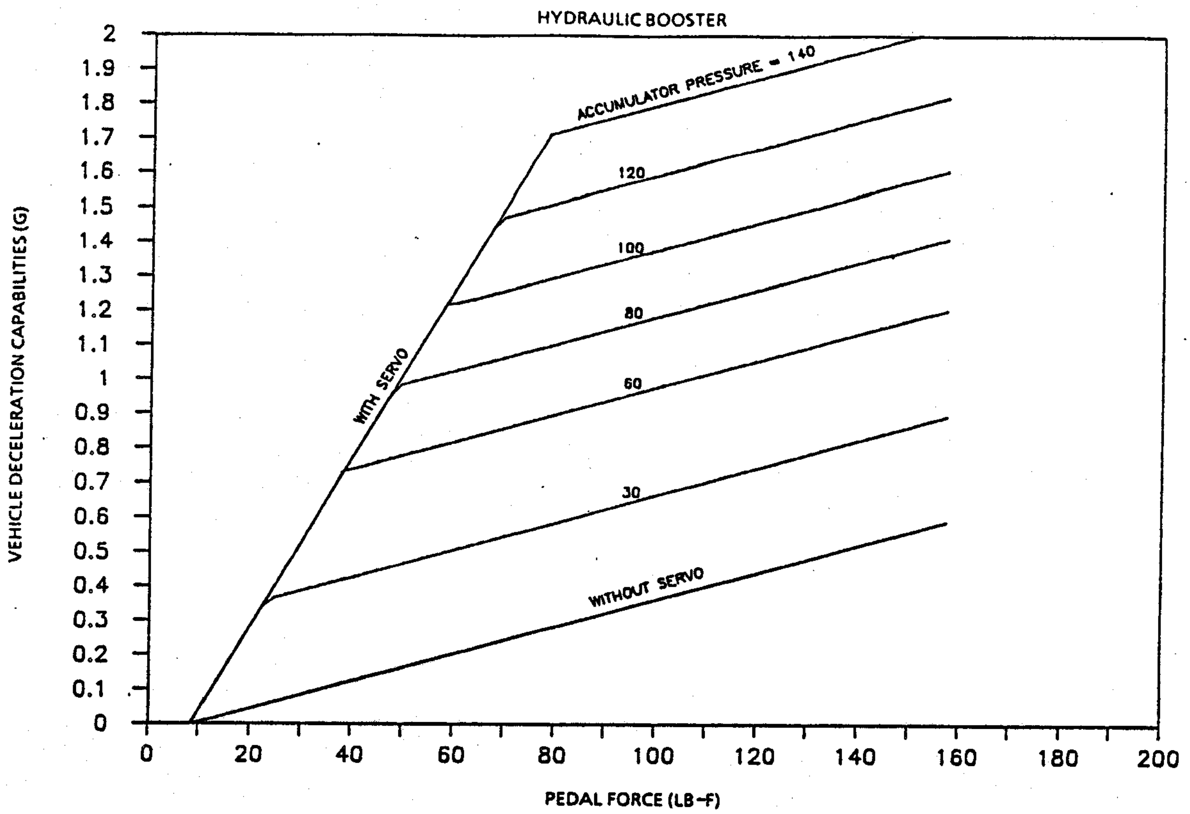


FIGURE C-13. DECELERATION CAPABILITY AS A FUNCTION OF PEDAL FORCE AND ACCUMULATOR PRESSURE

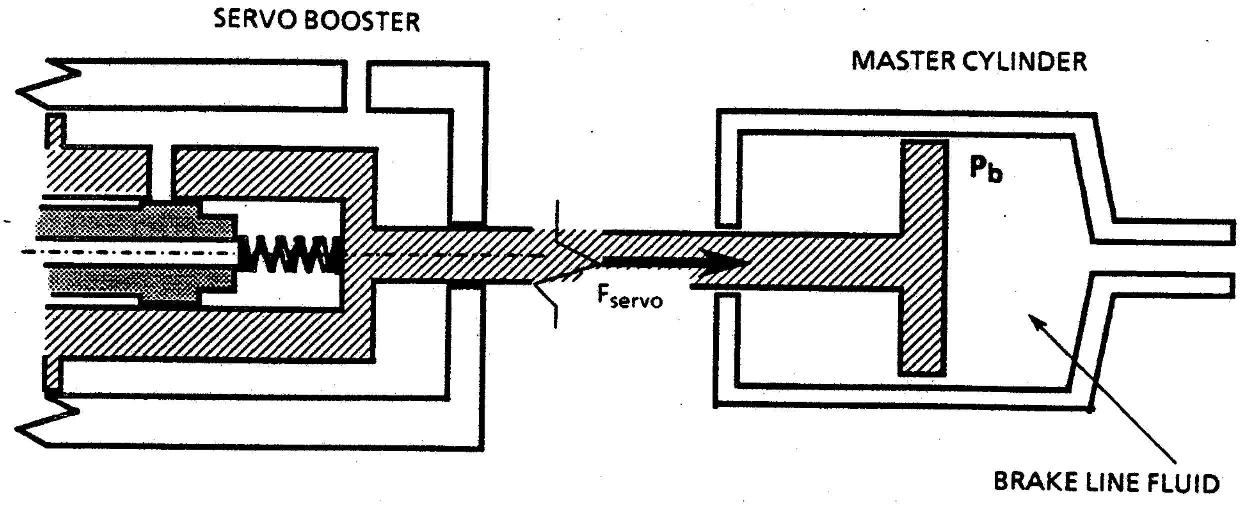


FIGURE C-14. SERVO BOOSTER-MASTER CYLINDER PISTONS

From the previous discussion, the boost force in the equilibrium can be written

$$F_b = F_s + F_a \qquad [C.17]$$

where F_s is the applied spool valve force and F_a is the assist chamber pressure force. Substituting Equation C.14 into the above equation, F_s is

$$F_s = \frac{F_a}{\frac{A_t}{A_s} - 1} \qquad [C.18]$$

from which the boost force is

$$F_b = F_a\left(1 + \frac{1}{\frac{A_t}{A_s - 1}}\right) = 1.28F_a \qquad [C.19]$$

The relationship between the accumulator pressure and the brake line pressure is

$$P_b = k'P_f\left[1 + \frac{1}{\frac{A_t}{A_s - 1}}\right] = 1.28k'P_f \qquad [C.20]$$

From this relationship and the data supplied by Audi, the valve of k' can be determined, from which the maximum brake pressure for any given supply pressure can be calculated. The maximum boost-assisted brake pressure for several supply pressures is given in Table C-1. Pedal force compared to pedal travel is shown in Figure C-15.

TABLE C-1. MAXIMUM BOOST-ASSISTED BRAKE PRESSURE

P_f (supply pressure) Bar	P_b (brake pressure) Bar
140	150
120	129
100	107
80	86
60	64
30	32
0	0

C.6 MECHANICAL EFFECTS TO DRIVER RESPONSE

Total brake failure would be obvious after an incident. In order for the system to completely fail, the hydraulic brake fluid must leak internally to the master cylinder or leak to the environment. Evidence of a failure would remain in such a closed hydraulic system. A low fluid level in the brake

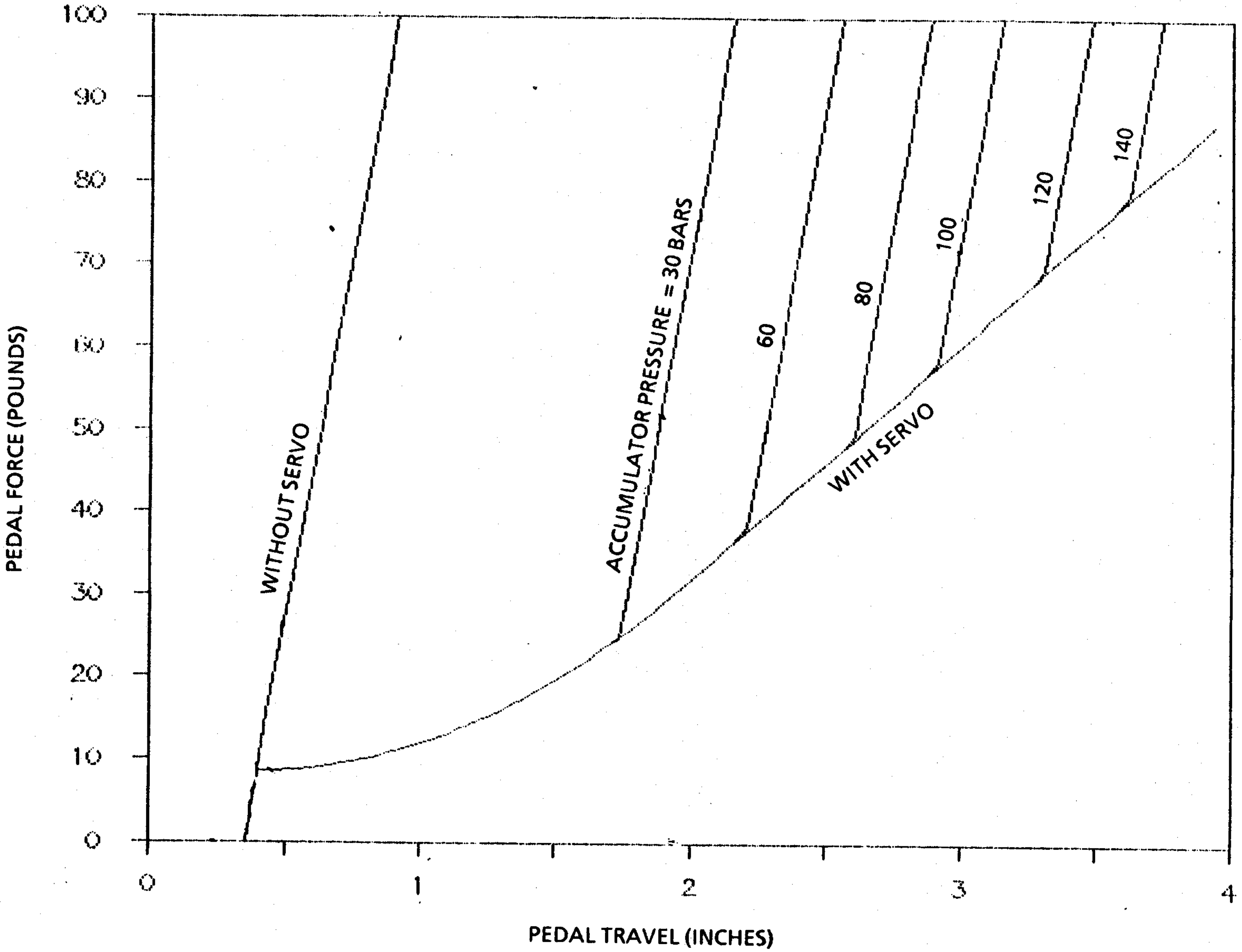


FIGURE C-15. PEDAL FORCE VERSUS PEDAL TRAVEL: HYDRAULIC BOOSTER fluid reservoir would indicate a system leak. In the case where the master cylinder leaked internally,the failure is not reversible and the brake system would still not operate after the incident.

The brake system's hydraulic power assist is capable of temporarily malfunctioning. If the power-assist system was to malfunction, the required brake-pedal pressure would be about 4.6 times the normal (assist working) braking force required. This would make the system seemingly unresponsive, but enough force could still be applied by the driver to stop the vehicle.

C.6.1 Servo Assist Malfunction and Recovery

One type of temporary failure of the hydraulic assist is reversible. If the brake accumulator was drained fully on start-up and the driver immediately shifted the vehicle into gear and pumped the brake pedal faster than the central hydraulic pump could restore the accumulator pressure, the assist would be inoperable (degraded). However, given time, the pump would restore the fluid level and pressure in the accumulator, and the brake-assist system would operate normally. The amount of time the system needs to restore the accumulator pressure and allow the power assist to operate normally depends upon the empty accumulator gas pressure.

LIST OF SYMBOLS

α = Hydraulic pump volumetric efficiency

Δ = Volume of fluid displaced per brake-pedal depression

A_a = Cross-sectional area of assist chamber

A_s = Cross-sectional area of spool valve chamber

A_t = Cross-sectional area of piston, total

F_b = Force applied by boost servo

F_s = Force applied to spool valve from brake pedal

F_{sv} = Force due to pressure in spool valve chamber

ΔF_{sv} = Change in force due to pressure in spool valve chamber

k = Proportionality constant

n = Exponent in ideal gas equation

N = Number of brake-pedal depressions

P = Hydraulic fluid or gas pressure

P_B = Pressure of gas in accumulator during bleed-down

P_E = Pressure of gas in accumulator empty

P_f = Fluid pressure in assist chamber

P_F = Pressure of gas in accumulator full

P_L = Pressure of gas in accumulator during loading

q = Volume flow rate from hydraulic pump

q_o = Volume flow rate from hydraulic pump at idle (850 RPM)

RPM = Engine speed (revolutions per minute)

V_E = Volume of gas in accumulator empty

V_F = Volume of gas in accumulator full

APPENDIX D

ENGINE SURGE RESULTS OF A TEST VEHICLE

D.1 INTRODUCTION

In late March 1987, NHTSA contacted TSC concerning a phoned-in complaint of an engine surging problem in a 1984 Audi 5000S. At the request of NHTSA a meeting was arranged with the owners of the vehicle to discuss the complaint and arrange for use of the car for evaluation. The following paragraphs discuss the complaint, tests, and results that TSC observed.

D.2 SUDDEN ACCELERATION HISTORY OF THE TEST VEHICLE

In an interview by TSC the owners reported the following:

The first incident that was noticed by Driver A occurred in November 1986. An abrupt engine surge was noticed right after a "cold start." A few weeks later, Driver A came out of a dry cleaners (warm engine) and started the car in park without being near the pedals; the car surged to approximately 4000 RPM. Driver A shut off the vehicle and started it again, and it appeared normal. Since then, the surges have become more frequent and sometimes occur with the car in gear.

The latest incident occurred in April at a red light with the car in gear. The incidents happen with the engine hot or cold, but seem to happen more often when the driver's foot is on the brake.

Driver B has also experienced engine surges, and during one incident allowed the vehicle to accelerate on its own. The speed went from approximately 20 or 25 mph to 35 mph in a short time before braking was necessary for traffic. Both drivers reported that they noticed repetitious surges (up and down engine speed in short intervals). The brakes have always worked.

During service in November 1986, the Audi dealer installed the shift-interlock. After complaining of the engine surges, the idle-stabilizer valve was replaced by the dealer in January. No other service relating to this problem has been performed. The events continued and may have gotten worse after the valve replacement.

D.3 VEHICLE

TSC examined the vehicle at the home of the owners. During a warm start (the car had been sitting for approximately 1 hour), the engine surged to 2500 RPM for 2 to 3 seconds after the engine had been running for 10 or 15 seconds. The engine was losing coolant and sounded as if it had an exhaust manifold leak. We also noted that the cruise control switch was "on" although the owners stated they seldom used the cruise control and normally left it on "off." The owners agreed to let TSC borrow the vehicle for testing.

D.4 TSC TESTS AND RESULTS

On April 13, the 1984 Audi 5000 was driven to TSC. During the drive the car performed routinely. After further examination, it was determined that the vehicle was in good condition except for the water pump and exhaust leaks previously noted. All other engine systems, including brakes and cruise control, appeared to function normally. The vehicle was instrumented with a portable computer to sample and record the inputs and outputs from the idle-stabilizer electronic control unit. This idle-stabilizer control unit is located under the dashboard (driver's side), and was manufactured by VDO (Part No. 44 3907393D).

The sample and recording system is shown in block diagram in Figure D-1. In order to observe transient phenomena, the computer was set to provide one sample every 1.3 seconds. Software was written to sample the inputs, which were 1) throttle position, 2) air-conditioner clutch, 3) engine temperature, 4) cruise control, 5) engine speed, and 6) the output to the idle-stabilizer valve. Inputs 1) through 4) are basically on-off switches and are recorded as 0 or 1 respectively. Engine speed was recorded in RPM and the output to the idle-stabilizer valve was recorded in amps. Approximately 3 days were required for installation and debugging of the sampling system. During this time (April 13 to 16), no engine surges were observed while running and driving the car. On the morning of April 16th (a cloudy, rainy day) the first surge was observed and recorded. Two other surges were observed that morning but were not recorded due to system problems. Other engine surges were observed and recorded on April 17, 18, and 19 as shown in the Table D-1 summary. In total, 10 incidents were observed and 7 recorded during approximately 30 hours of driving by 3 different TSC personnel over 5 days (including a weekend). The start-and-stop driving modes were emphasized as these seemed to be the conditions under which the engine surges were most likely to occur.

All inputs and output, as well as dates and times, were continuously recorded. Table D-2 is a summary of the seven recorded incidents showing the date, time, operator, and status of the various inputs and the output.

THR = throttle valve position
1 = closed   0 = open

A/C = air-conditioner clutch
1 = on   0 = off

TSE = engine temperature sensor
1 = <40°C   0 = >40°C

CRU = cruise control
1 = on   0 = off

TACH = engine speed in RPM

STAB = amperage to stabilizer valve (232 = 2.32 amps)

Table D-3 shows a more complete record before and after each incident. In all incidents, the output current to the coil of the idle-stabilizer valve increased to approximately 2.2 amps with no change in the status of the input signals. (The valve normally requires 1.3 amps to be fully opened.) Seven of the ten incidents occurred with the engine warm and the gear selector in park. Three incidents occurred with the gear selector in drive: one while under way (Incident #8) and two while stopped at a red light (Incidents #7 and #10). The incidents varied in time from 1 to 6 seconds. Incidents #4 and #7 were double incidents in that the amperage to the valve increased to 2.2 amps and then decreased for 1 second to normal (approximately 0.5 amps), and then suddenly increased again. In park, engine speed during the incidents increased from normal idle (750 to 800 RPM) to between 2500 RPM and

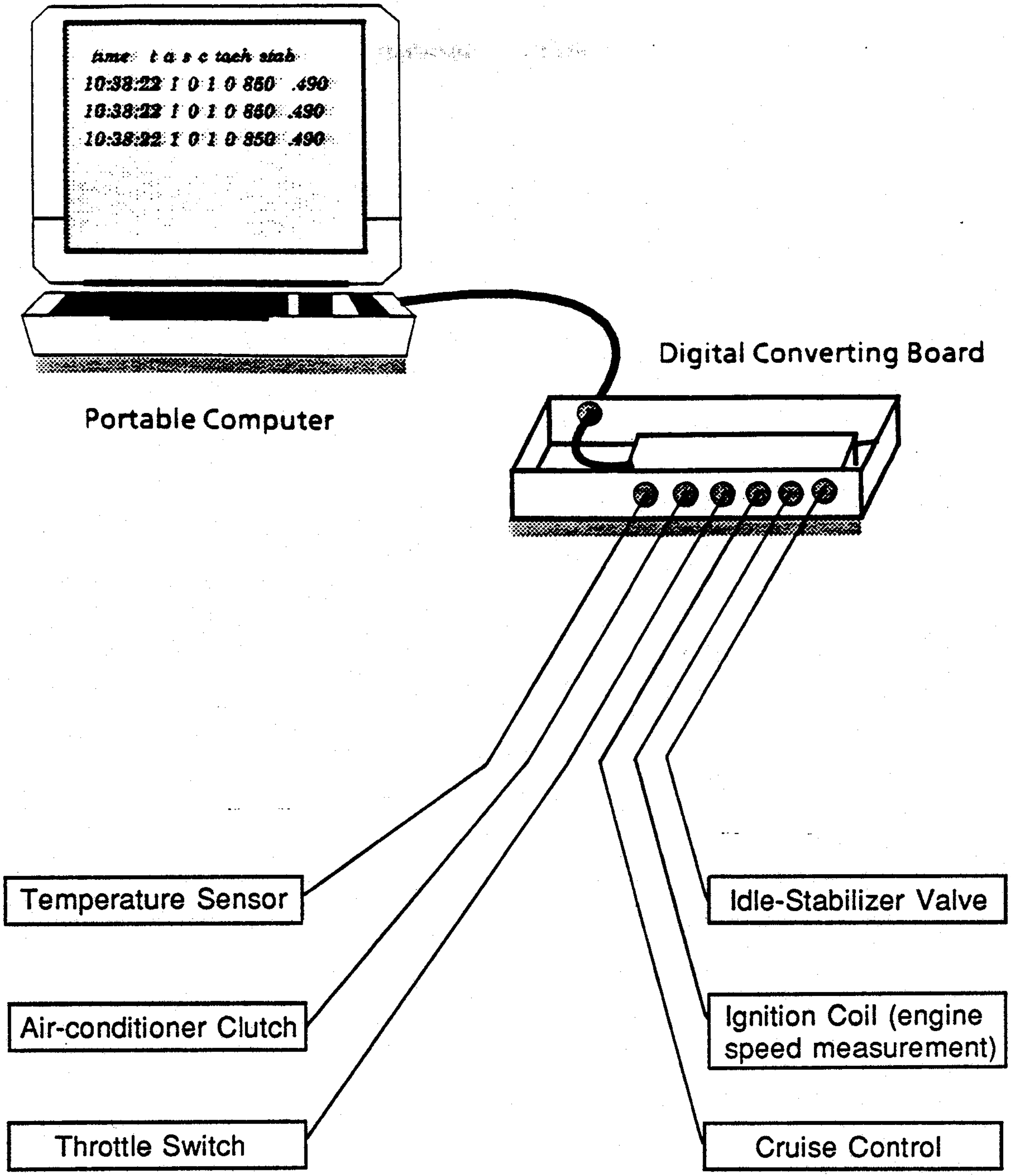


FIGURE D-1. SAMPLE AND RECORDING SYSTEM

TABLE D-1. ENGINE SURGE SUMMARY

Incident #	Date	Time	Gear	Comments
1	4/16/87	10:32:12 10:32:18	park	
2	4/16/87	14:29:00 14:29:00	park	not recorded board fault
3	4/16/87	14:29:00 14:29:00	park	not recorded board fault
4	4/16/87	14:56:17 14:56:25	park	
5	4/16/87	15:00:00 15:00:00	park	not recorded
6	4/16/87	15:20:28 15:20:29	park	
7	4/17/87	10:38:14 10:38:22	drive	stopped at red light
8	4/17/87	12:03:50 12:03:51	drive	throttle opened
9	4/18/87	15:21:56 15:21:58	park	
10	4/19/87	17:17:11 17:17:13	drive	

TABLE D-2. SUMMARY OF INCIDENTS

TIME	THR	A/C	TSE	CRU	TACH	STAB	DATE	OPERATOR
19:32:12	1	0	1	0	1128	232	04/16/87	CBW
19:32:14	1	0	1	0	2328	231	04/16/87	CBW
19:32:15	1	0	1	0	2664	231	04/16/87	CBW
19:32:16	1	0	1	0	2712	231	04/16/87	CBW
14:56:18	1	0	1	0	2304	222	04/16/87	CBW
14:56:22	1	0	1	0	1632	220	04/16/87	CBW
15:20:28	1	0	1	0	1032	226	04/16/87	CBW
10:38:17	1	0	1	0	1632	224	04/17/87	JKP
10:38:18	1	0	1	0	1752	224	04/17/87	JKP
10:38:20	1	0	1	0	1728	222	04/17/87	JKP
10:38:22	1	0	1	0	1800	221	04/17/87	JKP
12:03:51	0	0	1	0	3144	218	04/17/87	JKP
15:21:58	1	0	1	0	1032	211	04/20/87	GAC
17:17:13	1	0	1	0	840	200	04/20/87	GAC

TABLE D-3. COMPLETE RECORD BEFORE AND AFTER INCIDENT

INCIDENT #1

```
TIME      THR A/C TSE CRU TACH  STAB  DATE     OPERATOR
--------  --- --- --- --- ----- ----- -------- --------
19:32:06   1   0   1   0   1152    56 04/16/87 CBW
19:32:07   1   0   1   0   1032    52 04/16/87 CBW
19:32:09   1   0   1   0    984    47 04/16/87 CBW
19:32:10   1   0   1   0    744    53 04/16/87 CBW
19:32:11   1   0   1   0    744    56 04/16/87 CBW
19:32:12   1   0   1   0   1128   232 04/16/87 CBW
19:32:14   1   0   1   0   2328   231 04/16/87 CBW
19:32:15   1   0   1   0   2664   231 04/16/87 CBW
19:32:16   1   0   1   0   2712   231 04/16/87 CBW
19:32:18   1   0   1   0   2520    50 04/16/87 CBW
19:32:19   1   0   1   0    888    56 04/16/87 CBW
19:32:20   1   0   1   0    768    68 04/16/87 CBW
19:32:22   1   0   1   0   1152    47 04/16/87 CBW
19:32:23   1   0   1   0    768    52 04/16/87 CBW
19:32:24   1   0   1   0    768    53 04/16/87 CBW
19:32:25   1   0   1   0    840    50 04/16/87 CBW
19:32:27   1   0   1   0    816    51 04/16/87 CBW
19:32:28   1   0   1   0    840    50 04/16/87 CBW
19:32:29   1   0   1   0    816    51 04/16/87 CBW
19:32:31   1   0   1   0    792    50 04/16/87 CBW
19:32:32   1   0   1   0    792    49 04/16/87 CBW
19:32:33   1   0   1   0    768    50 04/16/87 CBW
19:32:35   1   0   1   0    840    49 04/16/87 CBW
19:32:36   1   0   1   0    792    51 04/16/87 CBW
19:32:37   1   0   1   0    864    50 04/16/87 CBW
19:32:38   1   0   1   0    816    49 04/16/87 CBW
19:32:40   1   0   1   0    816    50 04/16/87 CBW
```

TABLE D-3. COMPLETE RECORD BEFORE AND AFTER INCIDENT (continued)

INCIDENT #4

TIME	THR	A/C	TSE	CRU	TACH	STAB	DATE	OPERATOR
14:56:00	1	0	1	0	864	52	04/16/87	CBW
14:56:01	1	0	1	0	792	52	04/16/87	CBW
14:56:02	1	0	1	0	912	50	04/16/87	CBW
14:56:04	1	0	1	0	912	51	04/16/87	CBW
14:56:05	1	0	1	0	888	51	04/16/87	CBW
14:56:06	1	0	1	0	888	50	04/16/87	CBW
14:56:08	1	0	1	0	840	52	04/16/87	CBW
14:56:09	1	0	1	0	888	51	04/16/87	CBW
14:56:10	1	0	1	0	840	52	04/16/87	CBW
14:56:12	1	0	1	0	912	51	04/16/87	CBW
14:56:13	1	0	1	0	912	52	04/16/87	CBW
14:56:14	1	0	1	0	912	50	04/16/87	CBW
14:56:16	1	0	1	0	936	49	04/16/87	CBW
14:56:17	1	0	1	0	864	135	04/16/87	CBW
14:56:18	1	0	1	0	2304	222	04/16/87	CBW
14:56:20	1	0	1	0	3072	56	04/16/87	CBW
14:56:21	1	0	1	0	1416	48	04/16/87	CBW
14:56:22	1	0	1	0	1632	220	04/16/87	CBW
14:56:24	1	0	1	0	2712	50	04/16/87	CBW
14:56:25	1	0	1	0	1272	52	04/16/87	CBW
14:56:26	1	0	1	0	816	51	04/16/87	CBW
14:56:28	1	0	1	0	840	52	04/16/87	CBW
14:56:29	1	0	1	0	888	50	04/16/87	CBW
14:56:30	1	0	1	0	936	48	04/16/87	CBW
14:56:32	1	0	1	0	912	48	04/16/87	CBW

TABLE D-3. COMPLETE RECORD BEFORE AND AFTER INCIDENT (continued)
INCIDENT #6

TIME	THR	A/C	TSE	CRU	TACH	STAB	DATE	OPERATOR
15:20:15	1	0	1	0	720	44	04/16/87	CBW
15:20:16	1	0	1	0	792	44	04/16/87	CBW
15:20:17	1	0	1	0	792	48	04/16/87	CBW
15:20:19	1	0	1	0	792	46	04/16/87	CBW
15:20:20	1	0	1	0	768	45	04/16/87	CBW
15:20:21	1	0	1	0	744	45	04/16/87	CBW
15:20:23	1	0	1	0	768	45	04/16/87	CBW
15:20:24	1	0	1	0	720	45	04/16/87	CBW
15:20:25	1	0	1	0	720	46	04/16/87	CBW
15:20:27	1	0	1	0	816	44	04/16/87	CBW
15:20:28	1	0	1	0	1032	226	04/16/87	CBW
15:20:29	1	0	1	0	2832	46	04/16/87	CBW
15:20:31	1	0	1	0	912	46	04/16/87	CBW
15:20:32	1	0	1	0	792	45	04/16/87	CBW
15:20:33	1	0	1	0	744	45	04/16/87	CBW
15:20:34	1	0	1	0	768	44	04/16/87	CBW
15:20:36	1	0	1	0	720	45	04/16/87	CBW
15:20:37	1	0	1	0	744	45	04/16/87	CBW
15:20:39	1	0	1	0	720	43	04/16/87	CBW
15:20:40	1	0	1	0	744	45	04/16/87	CBW
15:20:41	1	0	1	0	720	44	04/16/87	CBW
15:20:42	1	0	1	0	744	46	04/16/87	CBW
15:20:44	1	0	1	0	720	46	04/16/87	CBW
15:20:45	1	0	1	0	744	45	04/16/87	CBW

TABLE D-3. COMPLETE RECORD BEFORE AND AFTER INCIDENT (continued)

INCIDENT #7

TIME	THR	A/C	TSE	CRU	TACH	STAB	DATE	OPERATOR
10:38:00	1	0	1	0	936	57	04/17/87	JKP
10:38:01	1	0	1	0	936	57	04/17/87	JKP
10:38:02	1	0	1	0	936	56	04/17/87	JKP
10:38:04	1	0	1	0	912	56	04/17/87	JKP
10:38:05	1	0	1	0	936	55	04/17/87	JKP
10:38:06	1	0	1	0	936	55	04/17/87	JKP
10:38:08	1	0	1	0	936	57	04/17/87	JKP
10:38:09	1	0	1	0	912	56	04/17/87	JKP
10:38:10	1	0	1	0	936	57	04/17/87	JKP
10:38:12	1	0	1	0	912	58	04/17/87	JKP
10:38:13	1	0	1	0	960	56	04/17/87	JKP
10:38:14	1	0	1	0	984	55	04/17/87	JKP
10:38:16	1	0	1	0	960	148	04/17/87	JKP
10:38:17	1	0	1	0	1632	224	04/17/87	JKP
10:38:18	1	0	1	0	1752	224	04/17/87	JKP
10:38:20	1	0	1	0	1728	222	04/17/87	JKP
10:38:21	1	0	1	0	1680	56	04/17/87	JKP
10:38:22	1	0	1	0	1800	221	04/17/87	JKP
10:38:24	0	0	1	0	2472	72	04/17/87	JKP
10:38:25	0	0	1	0	1944	47	04/17/87	JKP
10:38:26	0	0	1	0	1488	47	04/17/87	JKP
10:38:28	0	0	1	0	1416	53	04/17/87	JKP
10:38:29	1	0	1	0	1104	48	04/17/87	JKP
10:38:30	1	0	1	0	960	49	04/17/87	JKP
10:38:32	1	0	1	0	840	52	04/17/87	JKP
10:38:33	1	0	1	0	912	52	04/17/87	JKP
10:38:34	0	0	1	0	2232	47	04/17/87	JKP
10:38:36	0	0	1	0	2088	49	04/17/87	JKP
10:38:37	0	0	1	0	1776	48	04/17/87	JKP
10:38:38	0	0	1	0	1872	48	04/17/87	JKP
10:38:39	0	0	1	0	2016	47	04/17/87	JKP
10:38:41	0	0	1	0	2352	47	04/17/87	JKP
10:38:42	0	0	1	0	2328	45	04/17/87	JKP
10:38:43	0	0	1	0	2304	46	04/17/87	JKP
10:38:45	0	0	1	0	1536	51	04/17/87	JKP

TABLE D-3. COMPLETE RECORD BEFORE AND AFTER INCIDENT (continued)
INCIDENT #8

TIME	THR	A/C	TSE	CRU	TACH	STAB	DATE	OPERATOR
12:03:35	1	0	1	0	960	58	04/17/87	JKP
12:03:37	1	0	1	0	912	59	04/17/87	JKP
12:03:38	1	0	1	0	936	59	04/17/87	JKP
12:03:39	1	0	1	0	912	58	04/17/87	JKP
12:03:40	1	0	1	0	1200	47	04/17/87	JKP
12:03:42	0	0	1	0	2424	47	04/17/87	JKP
12:03:43	0	0	1	0	2784	48	04/17/87	JKP
12:03:44	0	0	1	0	2976	47	04/17/87	JKP
12:03:46	0	0	1	0	2808	48	04/17/87	JKP
12:03:47	0	0	1	0	2952	48	04/17/87	JKP
12:03:48	0	0	1	0	3024	45	04/17/87	JKP
12:03:50	0	0	1	0	3096	46	04/17/87	JKP
12:03:51	0	0	1	0	3144	218	04/17/87	JKP
12:03:52	0	0	1	0	2760	47	04/17/87	JKP
12:03:54	0	0	1	0	2592	47	04/17/87	JKP
12:03:55	0	0	1	0	2448	46	04/17/87	JKP
12:03:56	0	0	1	0	2352	48	04/17/87	JKP
12:03:58	0	0	1	0	1992	48	04/17/87	JKP
12:03:59	0	0	1	0	1872	47	04/17/87	JKP
12:04:00	0	0	1	0	1848	47	04/17/87	JKP
12:04:02	0	0	1	0	1896	47	04/17/87	JKP
12:04:03	0	0	1	0	1848	46	04/17/87	JKP
12:04:04	0	0	1	0	2184	47	04/17/87	JKP

TABLE D-3. COMPLETE RECORD BEFORE AND AFTER INCIDENT (continued)

INCIDENT #9

```
TIME      THR A/C TSE CRU TACH  STAB  DATE     OPERATOR
-------- --- --- --- --- ----- ----- -------- --------
15:21:55   1   0   1   0   888    52 04/20/87 GAC
15:21:56   1   0   1   0   912    53 04/20/87 GAC
15:21:58   1   0   1   0  1032   211 04/20/87 GAC
15:21:59   1   0   1   0   912    55 04/20/87 GAC
15:22:00   1   0   1   0   888    53 04/20/87 GAC
15:22:02   1   0   1   0   960    56 04/20/87 GAC
15:22:03   1   0   1   0   888    53 04/20/87 GAC
15:22:04   1   0   1   0   912    52 04/20/87 GAC
15:22:06   1   0   1   0   936    51 04/20/87 GAC
15:22:07   1   0   1   0   888    52 04/20/87 GAC
15:22:08   1   0   1   0   816    50 04/20/87 GAC
15:22:10   1   0   1   0   888    51 04/20/87 GAC
```

TABLE D-3. COMPLETE RECORD BEFORE AND AFTER INCIDENT (continued)

INCIDENT #10

TIME	THR	A/C	TSE	CRU	TACH	STAB	DATE	OPERATOR
17:17:01	1	0	1	0	744	53	04/20/87	GAC
17:17:02	1	0	1	0	816	54	04/20/87	GAC
17:17:03	1	0	1	0	792	56	04/20/87	GAC
17:17:05	1	0	1	0	744	54	04/20/87	GAC
17:17:06	1	0	1	0	816	55	04/20/87	GAC
17:17:07	1	0	1	0	864	57	04/20/87	GAC
17:17:09	1	0	1	0	816	55	04/20/87	GAC
17:17:10	1	0	1	0	816	56	04/20/87	GAC
17:17:11	1	0	1	0	792	57	04/20/87	GAC
17:17:13	1	0	1	0	840	200	04/20/87	GAC
17:17:14	1	0	1	0	816	55	04/20/87	GAC
17:17:15	1	0	1	0	840	57	04/20/87	GAC
17:17:17	1	0	1	0	864	55	04/20/87	GAC
17:17:18	1	0	1	0	768	54	04/20/87	GAC
17:17:19	1	0	1	0	840	54	04/20/87	GAC
17:17:21	1	0	1	0	1008	49	04/20/87	GAC
17:17:22	0	0	1	0	1032	49	04/20/87	GAC
17:17:23	1	0	1	0	744	55	04/20/87	GAC
17:17:25	1	0	1	0	792	54	04/20/87	GAC
17:17:26	0	0	1	0	1128	48	04/20/87	GAC

3000 RPM. During Incident #8 with the throttle open, the engine speed increased only slightly, and in fact, was not noticeable to the driver as he was accelerating up a hill. An increase of approximately 50 RPM was recorded during Incident #10, which was also hardly noticeable. In both of these "drive" incidents, the current increase was for only 1 second. The third "drive" incident (#7), however, was very apparent and occurred just before the driver accelerated from a red light.

TSC performed further tests to evaluate the effect of a fully opened idle-stabilizer valve on vehicle performance. For these tests, 1.3 amps of current were supplied to the stabilizer valve by a battery pack. A fully open valve caused this Audi to reach speeds of 45 mph in drive and 25 mph in reverse within 30 to 40 seconds. When the valve was opened at 60 mph the vehicle speed increased quickly to 65 mph and felt as if the cruise control had engaged. The electronic control box was examined and the components were found to be discolored, possibly due to excess heat; these components also exhibited a burnt odor.

APPENDIX E

DRIVER COMPARTMENT MEASUREMENTS: 1975-1981
DOMESTIC VEHICLES

NU	YR	MODEL	MILES	SER	ENG.	CRCT	A1	A2	A4	A5
1	81	PACER	16634	1AMCA0851BK146032	L-6	N	N	.	.	.
2	74	AMB	102591	A4A851H526158	V-8	N	N	.	.	.
3	74	MAT	98267	A4A161A767810	L-6	N	N	.	.	.
4	79	NY	4695	TH42K9B921306	V-8	Y	N	.	.	.
5	80	NEWP	21576	TM41GAF106715	V-8	N	N	.	.	.
6	80	CORD	33891	5H22GAD089541	V-8	Y	C/V	S	B	N
7	78	LEBARON	52681	FH22G8B523151	V-8	N	N			
8	76	IMP.	60001	VH22T6A542168	V-8	Y	C/V	S	B	N
9	74	N.Y	72136	CH42M4C671890	A	N	N	.	.	.
10	76	NEWP	91561	CM41M6C207152	V-8	N	N	.	.	.
11	80	ST.R	25725	EH43KAB210501	V-8	N	N	.	.	.
12	78	DIP	41861	GH22086126814	L-6	N	N	.	.	.
13	75	MONO	110423	DM41G5B532178	V-8	N	N	.	.	.
14	75	CORO	121011	WM21K5P115812	V-8	N	N	.	.	.
15	76	CHAR	62552	X522KGR113654	V-8	N	N	.	.	.
16	77	MONA	68562	DM41G7B891062	V-8	N	N	.	.	.
17	79	VOL	40415	HL41G9F123171	V-8	N	N	R	B	.
18	75	DART	98686	LM21C5F697541	L-6	N	N	.	.	.
19	77	FURY	82318	PH22G7A765126	V-8	N	N	.	.	.
20	73	FURY	145691	RL41M3A951232	V-8	N	N	.	.	.
21	78	CONT.	23414	8Y815876016	V-8	Y	N	.	.	.
22	79	MARK V	26322	F94895619344F	V-8	Y	N	.	.	.
23	79	VERS	33739	F9W84F654390F	V-8	Y	C/R	S	B	.
24	75	MK.IV	72652	F5Y894089F	V-8	Y	C	S	B	.
25	79	GAL	52302	F9A63F144853F	V-8	N	N	.	.	.
26	73	LTD	89088	F97B63S276874F	V-8	N	N	.	.	.
27	76	GAL	103352	6B765194932	V-8	N	N	.	.	.
28	80	LTD2	39651	BE71BA678125	V-8	N	N	.	.	.
29	80	TBIR	41565	FT71BA153478	V-8	Y	N	.	.	.
30	74	TBIR	125678	4Y87A115130	V-8	N	N	.	.	.
31	73	TOR	78028	44425218914F	V-8	N	N	.	.	.
32	76	MAV	61478	FOE91612625	L-6	N	N	.	.	.
33	80	FRMT	42589	OE91A126801	L-4	N	N	.	.	.
34	79	GRAN	48961	OF9191160895	L-6	N	N	.	.	.
35	81	MARQ	10291	1MEBP83F9CZ625031	V-8	N	N	.	.	.
36	76	MARQ	50248	6274S527622	V-8	N	N	.	.	.
37	73	MONT	138164	3B62A514151	V-8	N	N	.	.	.
38	73	MONT	116688	3401L340962	V-8	N	N	.	.	.
39	79	COUG	57950	9H93H942332	V-8	N	N	.	.	.
40	78	DEV	67118	6D6958Q111516	V-8	Y	V	S	B	N
41	79	SEV	51233	6569B9Q243571	V-8	Y	V/C	F	B	N
42	79	ELD	81679	6L47T9Q235141	V-8	Y	V/C	F	R	N
43	77	FLW	41115	6F2357Q688115	V-8	Y	V/C	S	B	N
44	73	ELD	121677	6EL67R3Q221541	V-8	Y	N	.	.	.
45	73	CALA	101533	6CC49R39198215	V-8	N	N	.	.	.
46	80	CAP	35069	1N47GAF268105	V-8	N	N	.	.	.
47	79	IMP	42567	L47G95293881	V-8	N	N	.	.	.
48	79	MALI	27570	IT27M9B067881	V-8	N	N	.	.	.
49	80	M.C	51727	1M477AF952110	V-6	N	N	.	.	.
50	73	CAP	101067	1H47K5P174999	V-8	Y	N	.	.	.
51	73	IMP	130711	1I44H3PO67118	V-8	N	N	.	.	.
52	76	M.C	57276	1H57U6B6078081	V-8	N	N	.	.	.

NU	YR	MODEL	B1	B2	B3	B4	C1	C2	P1	P2	P3	A
1	81	PACER	20	17	19	20	.	.	5.1	6	6.8	22
2	74	AMB	19	16	17	22	.	.	5.4	6.1	6.9	15
3	74	MAT	18	14	16	16	.	.	5.3	6.1	7	20
4	79	NY	25	27	27	26	.	.	5	8.1	10	25
5	80	NEWP	21	14	13	19	.	.	6.1	8.1	10.2	35
6	80	CORD	20	20	19	16	N	N	4.2	5.6	7	11
7	78	LEBARON	20	20	16	18	N	N	5	5.8	7.1	12
8	76	IMP.	28	28	24	26	N	N	6.8	7.9	9	24
9	74	N.Y	20	20	12	19	.	.	6	7.3	8.6	25
10	76	NEWP	15	15	15	15	.	.	6.1	7	7.9	25
11	80	ST.R	19	19	22	26	.	.	5	8	9.4	25
12	78	DIP	14	14	12	13	.	.	4.2	5	6.1	23
13	75	MONO	0	0	16	13	.	.	4.7	5.9	6.5	20
14	75	CORO	9	9	9	12	.	.	4.5	6	6.9	25
15	76	CHAR	13	13	13	13	.	.	3.8	5	6.7	-45
16	77	MONA	16	16	14	12	.	.	4.6	5.8	6.9	5
17	79	VOL	16	12	13	13	N	N	3	3.8	4.2	15
18	75	DART	15	14	16	16	.	.	4.8	5.9	7	15
19	77	FURY	18	15	15	16	.	.	6.7	9	11.1	15
20	73	FURY	0	0	0	0	.	.	5	6.5	8.2	0
21	78	CONT.	25	25	26	30	.	.	5.7	8	11	20
22	79	MARK V	28	28	27	36	.	.	6	6.8	7.9	20
23	79	VERS	20	22	22	21	Y4	Y4	4.2	5.1	5.9	20
24	75	MK.IV	21	21	21	25	.	.	5.4	7.1	8	20
25	79	GAL	0	0	0	16	.	.	3.9	4.9	6.1	25
26	73	LTD	16	16	15	13	.	.	5.1	6.8	9	15
27	76	GAL	0	0	0	0	.	.	4	5.9	7.8	20
28	80	LTD2	30	32	30	31	.	.	3	5	8	9
29	80	TBIR	30	32	30	31	.	.	4	7	9	9
30	74	TBIR	28	78	26	31	.	.	6.8	9	11	15
31	73	TOR	18	18	17	19	.	.	5.4	6.7	8.1	68
32	76	MAV	26	27	25	26	.	.	4	6	7	9
33	80	FRMT	26	26	29	28	.	.	4	5.5	9	10
34	79	GRAN	25	25	18	28	.	.	6.7	8.1	9.3	10
35	81	MARQ	30	31	31	33	.	.	6	8.1	9.4	-20
36	76	MARQ	19	19	22	22	.	.	6.7	9.1	10	73
37	73	MONT	13	13	15	16	.	.	7	8.3	9.8	76
38	73	MONT	20	20	20	19	Y4	Y4	5	7.1	8.6	54
39	79	COUG	22	22	19	19	.	.	5.8	7	8.3	76
40	78	DEV	32	32	33	34	Y4	Y4	6.8	8	9.9	32
41	79	SEV	0	0	0	24	Y5	Y5	7.3	9.8	12.4	80
42	79	ELD	0	0	0	22	Y5	Y5	8	9.6	14.1	80
43	77	FLW	0	0	29	34	Y5	Y5	8.1	9.3	10.9	41
44	73	ELD	0	0	0	31	.	.	8.6	10.2	13.9	81
45	73	CALA	0	0	0	19	.	.	8.5	9.8	11	0
46	80	CAP	0	0	0	13	.	.	5.3	6.8	9.1	45
47	79	IMP	0	0	0	10	.	.	6	8.3	9.5	45
48	79	MALI	14	15	14	14	.	.	3.1	4	5.2	-35
49	80	M.C	16	16	15	19	.	.	3.3	4.1	5.5	-35
50	73	CAP	12	12	13	15	.	.	5.1	6	7.6	80
51	73	IMP	0	0	0	13	.	.	4.9	5.5	6.2	45
52	76	M.C	0	0	0	15	.	.	5	6.2	8	40

NU	YR	MODEL	B	C	D1	D2	E	F	G1	G2
1	81	PACER	47	47	18	14	142	59	90	40
2	74	AMB	54	48	11	21	121	57	86	52
3	74	MAT	55	48	14	19	121	57	90	50
4	79	NY	70	40	5	10	100	40	40	22
5	80	NEWP	85	40	20	5	100	40	39	25
6	80	CORD	70	50	5	6	100	40	40	21
7	78	LEBARON	70	50	10	11	100	40	48	23
8	76	IMP.	72	90	20	21	99	40	40	17
9	74	N.Y	70	80	20	21	100	40	40	19
10	76	NEWP	70	40	20	21	100	40	39	13
11	80	ST.R	70	50	0	8	100	40	43	18
12	78	DIP	70	40	0	5	100	40	46	21
13	75	MONO	70	50	9	0	100	40	47	23
14	75	CORO	70	50	6	7	100	40	55	9
15	76	CHAR	70	50	0	6	100	40	50	25
16	77	MONA	70	50	4	2	100	40	45	30
17	79	VOL	70	50	0	0	100	40	50	5
18	75	DART	70	50	0	6	100	40	43	28
19	77	FURY	70	40	6	7	100	40	40	8
20	73	FURY	70	50	6	7	100	40	50	19
21	78	CONT.	49	40	5	11	155	39	76	35
22	79	MARK V	48	40	10	11	155	40	80	43
23	79	VERS	48	40	0	0	155	39	58	33
24	75	MK.IV	48	40	11	16	155	39	70	42
25	79	GAL	60	23	10	11	155	38	77	22
26	73	LTD	60	23	10	9	155	39	76	15
27	76	GAL	48	40	25	12	155	39	80	38
28	80	LTD2	51	30	11	6	135	65	73	58
29	80	TBIR	52	30	11	6	135	65	76	52
30	74	TBIR	51	40	22	12	155	39	65	41
31	73	TOR	56	40	29	26	155	39	48	21
32	76	MAV	72	30	16	12	135	49	96	65
33	80	FRMT	73	40	25	17	155	39	82	70
34	79	GRAN	68	40	28	26	155	39	88	52
35	81	MARQ	67	40	16	10	155	50	77	29
36	76	MARQ	67	40	28	11	155	39	81	42
37	73	MONT	68	40	28	14	155	50	78	45
38	73	MONT	67	40	10	9	155	39	72	49
39	79	COUG	65	40	9	12	135	50	83	51
40	78	DEV	73	79	18	12	233	61	69	56
41	79	SEV	64	78	61	52	195	67	69	33
42	79	ELD	63	78	66	58	195	67	66	38
43	77	FLW	69	68	25	14	231	46	48	32
44	73	ELD	61	65	50	10	231	42	48	21
45	73	CALA	60	65	50	10	233	47	45	15
46	80	CAP	67	70	0	10	233	60	63	20
47	79	IMP	67	70	0	10	150	60	63	20
48	79	MALI	56	37	10	12	135	47	64	3
49	80	M.C	56	37	10	12	135	47	65	5
50	73	CAP	45	70	6	6	150	65	59	28
51	73	IMP	79	67	10	10	150	65	50	30
52	76	M.C	76	47	10	0	137	57	58	23

NU	YR	MODEL	G3	G1A	G2A	G3A	BRK
1	81	PACER	10	.	.	.	M*
2	74	AMB	16	.	.	.	M
3	74	MAT	19	.	.	.	M
4	79	NY	7	40	5	-10	.
5	80	NEWP	10	39	10	-7	.
6	80	CORD	6	40	12	0	.
7	78	LEBARON	10	48	8	-11	.
8	76	IMP.	2	40	5	-9	.
9	74	N.Y	3	40	6	-10	.
10	76	NEWP	5	37	4	-10	.
11	80	ST.R	2	43	3	-13	.
12	78	DIP	6	46	21	6	.
13	75	MONO	0	47	12	-11	.
14	75	CORO	-5	55	9	-40	.
15	76	CHAR	19	50	25	-30	.
16	77	MONA	0	45	30	0	.
17	79	VOL	-50	50	-5	-90	.
18	75	DART	2	0	0	0	M
19	77	FURY	-20	40	0	-35	.
20	73	FURY	-8	50	0	-48	.
21	78	CONT.	15	76	21	7	.
22	79	MARK V	26	80	38	15	.
23	79	VERS	18	58	24	8	.
24	75	MK.IV	28	70	31	11	.
25	79	GAL	-7	77	-1	-32	.
26	73	LTD	-10	76	-5	-30	.
27	76	GAL	10	80	21	-21	.
28	80	LTD2	28	73	32	-1	.
29	80	TBIR	30	76	33	0	.
30	74	TBIR	28	65	32	19	.
31	73	TOR	11	48	13	4	.
32	76	MAV	33	.	.	.	.
33	80	FRMT	51	82	59	35	.
34	79	GRAN	30	88	43	21	.
35	81	MARQ	12	77	10	-11	.
36	76	MARQ	21	81	32	10	.
37	73	MONT	28	78	31	16	.
38	73	MONT	29	72	38	18	.
39	79	COUG	29	83	43	29	.
40	78	DEV	39	69	41	21	.
41	79	SEV	8	69	14	-6	.
42	79	ELD	10	66	19	-2	.
43	77	FLW	14	48	23	6	.
44	73	ELD	0	48	3	-21	.
45	73	CALA	-20	45	0	-45	.
46	80	CAP	-8	63	14	-35	.
47	79	IMP	-5	63	-11	-30	.
48	79	MALI	-20	64	-10	-40	.
49	80	M.C	-22	65	5	-22	.
50	73	CAP	-5	59	10	-35	.
51	73	IMP	-10	50	17	-40	.
52	76	M.C	0	58	6	-25	.

NU	YR	MODEL	MILES	SER	ENG.	CRCT	A1	A2	A4	A5
53	76	CHEV	89115	1629U6F331215	V-8	N	N	.	.	.
54	76	NOVA	84582	1X27U6W431542	V-8	N	N	.	.	.
55	76	CAM	82066	1Q87Q681372	V-8	N	N	.	.	.
56	73	CORV	85610	1767H3D	V-8	N	R	S	R	MO
57	79	LESAB	91327	4N69R9X301210	V-8	N	N	.	.	.
58	77	ELEC	56166	4U69R7Q871162	V-8	N	C/V	S	B	N
59	79	RIVI	32324	4257R9E139282	V-8	Y	N	.	.	.
60	81	CENTU	3721	1G4AH69A1BH106081	V-6	N	V	S	R	N
61	79	REGAL	57822	4J47G9X267110	V-6	N	N	.	.	.
62	75	LESAB	102716	4DN3955Q300715	V-8	N	N	.	.	.
63	76	ELEC	88177	4U39S6X277132	V-8	N	N	.	.	.
64	76	RIV	108701	4287T6X321892	V-8	N	R	S	B	HO
65	76	CENT	83216	4D29C6X452634	V-6	N	N	.	.	.
66	78	CR88	47110	3Q35N8X190261	V-8	N	R	S	D	N
67	80	98	33383	3X69RAX391232	V-8	N	N	.	.	.
68	76	98	100671	3L39R6M197651	V-8	N	N	.	.	.
69	75	98	135688	3U39T5M100677	V-8	N	N	.	.	.
70	78	CUTL	59701	3R47A8240701	V-6	N	N	.	.	.
71	76	CUTL	129073	3J57R6G221310	V-8	N	R	S	D	MH
72	79	TOR	51161	3257R9X729761	V-8	Y	N	.	.	.
73	73	TOR	160715	3Y57W3M297301	V-8	Y	N	.	.	.
74	79	BONN	67781	2N69R9P102136	V-8	N	N	.	.	.
75	80	CAT	20001	2L69RAP865123	V-8	N	R	S	R	MO
76	75	BONN	99109	2P47R5P388671	V-8	N	R	S	B	SO
77	75	CAT	74910	2L69R5P526911	V-8	N	V	S	R	MO
78	73	GP	101433	2K57T3A187945	V-8	N	N	.	.	.
79	80	GP	25111	2H37TAP327101	V-8	N	V	S	R	SO
80	79	LEMAN	14025	2F27A91539920	V-6	N	N	.	.	.
81	75	LEMAN	53519	2D29H5P306519	V-8	N	R	S	R	SO
82	77	OMEGA	50121	3B27G7M371940	V-8	N	N	.	.	.
83	73	APOLL	85514	4XC69D5X220749	L-6	N	N	.	.	.
84	76	STARF	75960	3D0766X292465	L-6	N	R	S	B	N

AVERAGE	68521.2
COUNT	85
MAX	160715
MIN	0
STD	36206.4
SUM	5824308
VAR	1E+09

NU	YR	MODEL	B1	B2	B3	B4	C1	C2	P1	P2	P3	A
53	76	CHEV	0	0	0	18	.	.	6.7	8.1	9.7	27
54	76	NOVA	15	15	13	19	Y4	Y4	3	4	5.1	33
55	76	CAM	11	10	11	12	.	.	2	4	4.5	40
56	73	CORV	16	16	17	17	.	.	5	6.2	8	-40
57	79	LESAB	0	0	0	21	.	.	7.3	8.6	10	27
58	77	ELEC	0	0	0	33	Y4	Y4	7.6	9.1	12.3	71
59	79	RIVI	0	15	0	0	.	.	7.5	9	15	80
60	81	CENTU	11	19	18	21	.	.	4.1	7	8.5	8
61	79	REGAL	21	19	18	18	.	.	6.8	8.1	9.8	8
62	75	LESAB	0	0	0	21	.	.	7.8	9.2	10.1	73
63	76	ELEC	0	0	0	24	.	.	7.6	9.3	10.6	73
64	76	RIV	0	0	0	27	Y3	Y3	8	10.1	13.8	5
65	76	CENT	0	18	0	19	.	.	5	7.2	8.6	42
66	78	CR88	0	0	0	34	Y1	Y3	7	10.5	14	0
67	80	98	0	0	0	28	.	.	6.7	8.9	12.1	0
68	76	98	14	13	14	15	Y2	Y2	7	9.6	11.1	88
69	75	98	0	0	0	26	.	.	8.1	9.7	10.1	78
70	78	CUTL	21	13	21	15	.	.	2	4.5	9	8
71	76	CUTL	16	14	15	16	Y4	Y4	4.2	6.7	8.9	35
72	79	TOR	0	0	0	16	.	.	7.8	9.1	12	80
73	73	TOR	0	0	0	21	.	.	6.7	5.8	13	33
74	79	BONN	0	0	0	19	.	.	6.2	7.5	9.1	25
75	80	CAT	0	0	0	31	Y3	Y3	6.5	9.1	12.8	5
76	75	BONN	18	18	21	18	Y3	Y3	8.7	10.1	12.1	60
77	75	CAT	0	0	18	19	Y3	Y3	4.8	7.6	8.5	25
78	73	GP	0	0	17	19	.	.	5	8	9	20
79	80	GP	20	21	19	23	Y3	Y3	6.3	8.1	9.1	22
80	79	LEMAN	0	0	0	24	.	.	6.7	9.1	11	22
81	75	LEMAN	15	16	16	18	Y3	Y2	5	7.1	9	41
82	77	OMEGA	18	18	18	22	.	.	4.6	6.9	8.6	-7
83	73	APOLL	16	16	16	19	.	.	6.1	8.6	11.1	70
84	76	STARF	17	17	18	21	2	2	4.5	7	9.1	-8
AVERAGE			12.1	12.8	12.6	19.9			5.6	7.2	9.0	28.0
COUNT			85	85	85	85			85	85	85	85
MAX			32	78	33	36			8.7	10.5	15	88
MIN			0	0	0	0			0	0	0	-45
STD			10.3	12.3	10.0	7.6			1.6	1.9	2.5	29.8
SUM			1026	1091	1075	1692			472.3	611.8	765.6	2384
VAR			106.4	151.5	99.7	58.6			2.7	3.4	6.2	886.2

NU	YR	MODEL	B	C	D1	D2	E	F	G1	G2
53	76	CHEV	68	73	74	0	152	60	58	38
54	76	NOVA	70	40	6	11	135	47	69	10
55	76	CAM	58	47	5	5	142	55	36	10
56	73	CORV	60	47	0	0	155	57	55	30
57	79	LESAB	71	68	75	0	152	60	62	21
58	77	ELEC	67	79	0	11	248	61	67	33
59	79	RIVI	63	77	66	58	195	67	60	28
60	81	CENTU	71	56	11	0	137	63	80	33
61	79	REGAL	71	56	15	6	137	63	75	46
62	75	LESAB	60	75	26	9	225	67	56	32
63	76	ELEC	60	75	23	11	225	67	60	35
64	76	RIV	76	79	8	68	233	61	62	39
65	76	CENT	75	68	14	12	155	59	63	38
66	78	CR88	73	79	32	40	233	61	63	25
67	80	98	72	79	15	8	227	61	67	30
68	76	98	45	70	6	7	150	65	62	38
69	75	98	57	77	22	11	248	60	55	33
70	78	CUTL	61	55	16	0	135	61	75	53
71	76	CUTL	75	70	10	10	155	59	55	32
72	79	TOR	63	77	66	58	195	67	64	33
73	73	TOR	74	79	10	0	248	60	60	24
74	79	BONN	177	70	11	13	150	59	68	49
75	80	CAT	72	80	56	37	248	61	65	29
76	75	BONN	86	62	5	7	163	60	60	12
77	75	CAT	176	68	0	3	152	60	60	47
78	73	GP	180	55	0	6	155	60	59	45
79	80	GP	156	68	15	16	155	55	68	33
80	79	LEMAN	156	79	15	16	248	60	68	39
81	75	LEMAN	75	47	15	13	137	59	61	39
82	77	OMEGA	85	30	14	15	98	59	63	41
83	73	APOLL	101	56	12	16	137	47	80	39
84	76	STARF	42	20	14	15	98	59	59	42
AVERAGE			70.7	54.1	17.1	13.24	152.69	51.05	61.6	31.4
COUNT			85	85	85	85	85	85	85	85
MAX			180	90	75	68	248	67	96	70
MIN			0	0	0	0	0	0	0	0
STD			27.6	17.9	17.8	13.57	48.006	11.71	15.4	14.4
SUM			6013	4601	1451	1126	12979	4340	5239	2671
VAR			762.3	321.0	317.6	184.3	2304.6	137.2	237.7	206.9

```
NU YR MODEL       G3   G1A   G2A   G3A BRK

53 76 CHEV        20    58    27     9 .
54 76 NOVA         5    69     5    -8 .
55 76 CAM        -21    36     0   -21 .
56 73 CORV         0    55    10   -25 .
57 79 LESAB      -5     62    11   -30 .
58 77 ELEC        14    67    18     5 .
59 79 RIVI         8    60     0   -17 .
60 81 CENTU       21    80    21     0 .
61 79 REGAL       19    75    35     5 .
62 75 LESAB       21    56    22    11 .
63 76 ELEC        21    60    28    17 .
64 76 RIV         22    62    26    14 .
65 76 CENT        16    63    21    -2 .
66 78 CR88        -8    63     0   -57 .
67 80 98          12    67    16     0 .
68 76 98          18    62    27     5 .
69 75 98          20    55    21    12 .
70 78 CUTL        35    75    26    -2 .
71 76 CUTL         5    55    26    -1 .
72 79 TOR         11    64    10    -8 .
73 73 TOR          9    60    16    -3 .
74 79 BONN        29    68    29     3 .
75 80 CAT         12    65    14    -3 .
76 75 BONN       -21    60     4   -29 .
77 75 CAT         26    60    31     8 .
78 73 GP          21    59    24     9 .
79 80 GP          16    68    19     0 .
80 79 LEMAN       13    68    23    -4 .
81 75 LEMAN       12    61    27     3 .
82 77 OMEGA       18    63    32     6 .
83 73 APOLL       18    80    26     4 .
84 76 STARF       20     .     .     . M

AVERAGE          9.8  56.1  16.1  -7.0
COUNT             85    85    85    85
MAX               51    88    59    35
MIN              -50     0   -11   -90
STD             16.2  20.8  14.0  20.5
SUM              832  4773  1366  -593
VAR            262.1 433.0 195.5 419.5
```

APPENDIX F

DRIVER COMPARTMENT MEASUREMENTS: 1984-1985 VEHICLES

MAKE	MODEL	YR	VINNO	LOCATION	DATE	CYL	SEAT
AUDI	4000S	82	WAUFA081XCA046192	CONCORD	10/22/86	4	BUC
AUDI	4000S	84	WAUFA0817EA041826	CONCORD	10/15/86	4	BUC
AUDI	400S	83	WAUFA0811DA136056	CONCORD	11/12/86	5	BUC
AUDI	5000	84	WAUFB0444EN112406	CONCORD	10/20/86	5	BUC
AUDI	5000S	84	WAUFBO449ENO80617	.	12/15/86	5	BUC
AUDI	5000 TURBO	82	WAUGH0436CN065158	CONCORD	10/14/86	5	BUC
AUDI	5000 TURBO	86	WAUHDO449GNO69462	CONCORD	12/05/86	5	BUC
BUICK	RIVERA	85	IG4EZ5745FE400664	CONCORD	.	8	BUC
CADILLAC	COUPE DEVLL	85	1G6CD4781F4203083	.	.	8	BEN
CADILLAC	ELDORADO	85	1G6EL6789FE609954	CONCORD	11/25/86	6	BUC
CADILLAC	FLEETWOOD	85	1G6CB6980F4252905	CONCORD	.	8	BUC
CHEVY	CAMARO	85	1G1FP87S5FN106508	CONCORD	11/26/86	6	BUC
CHEVY	CAMARO	85	1G1FP87S6FL457231	CONCORD	11/5/86	6	BUC
CHEVY	CAMARO	85	1G1FP8757FH118614	CONCORD	11/10/86	6	BUC
CHEVY	CAPRICE CLAS	85	1G1BN69Z7FH118614	CONCORD	10/21/86	6	BUC
CHEVY	CAVALIER	85	1G1JC69P9FJ212700	CONCORD	11/18/86	4	BUC
CHEVY	CAVALIER	85	1G1JD69P1FJ165188	CONCORD	11/12/86	5	BUC
CHEVY	CAVALIER	85	IGIJD35PIFJ129098	CONCORD	12/14/86	4	BUC
CHEVY	CAVALIER	85	1G1JB69P2FJ159870	CONCORD	11/18/86	4	BUC
CHEVY	CELEBRITY	85	IGIAWI9RXFG147557	CONCORD	.	4	BEN
CHEVY	CELEBRITY	85	IGIAW19R2FG138593	CONCORD	.	4	BEN
CHEVY	CELEBRITY	85	1G1AW19X7FG130780	CONCORD	11/5/86	6	BUC
CHEVY	CELEBRITY	85	1G1AW19R7F6120218	CONCORD	10/22/86	4	BUC
CHEVY	CELEBRITY	85	1G1AW19R7FG117893	CONCORD	11/18/86	4	BEN
CHEVY	MONTE CARLO	85	1G1GZ37ZOFR199560	CONCORD	11/12/86	6	BUC
CHEVY	MONTE CARLO	85	1G1GZ37Z4FR142178	CONCORD	12/2/86	6	BUC
CHEVY	MONTE CARLO	85	1G1G237G7FR170247	CONCORD	10/20/86	8	BUC
CHEVY	MONTE CARLO	85	1G1GZ37Z9FR142760	CONCORD	12/1/86	6	BUC
CHEVY	NOVA	85	1Y1SK19486Z109452	CONCORD	11/12/86	4	BUC
CHEVY	CAMARO	85	IGIFP8759FN132433	CONCORD	.	6	BUC
FORD	ESCORT	85	2FABPO941FB103158	CONCORD	11/10/86	4	BUC
FORD	ESCORT	85	IFABPI347FTJI5667	CONCORD	.		BUC
FORD	ESCORT	85	1FABP0422FR154061	CONCORD	11/10/86	4	BUC
FORD	LTD	85	1FAB393366140697	CONCORD	11/17/86	6	BUC
FORD	LTD	85	1FABP3937FG176570	CONCORD	11/3/86	6	BUC
FORD	LTD	85	1FABP3932GG137516	CONCORD	11/11/86	6	BUC
FORD	LTD	85	1FABP3934GG142608	CONCORD	11/11/86	6	BUC
FORD	MARK IV	85	1MRBP98FY742943	CONCORD	11/3/86	8	BUC
FORD	MARK IV	85	1MRBP98F2FY742943	CONCORD	11/4/86	8	BUC
FORD	MUSTANG	85	FABP2737GF278939	CONCORD	.	6	BUC
FORD	MUSTANG LX	85	1FABPZ6A26F178019	CONCORD	11/5/86	4	BUC
FORD	MUSTANG LX	85	IFABP28A3FF197805	CONCORD	10/21/86	4	BUC
FORD	TEMPO	85	1FABP22XXFK143583	CONCORD	10/27/86	4	BUC
FORD	TEMPO	85	1FABP23XXFK237798	CONCORD	11/4/86	4	BUC
FORD	TEMPO	85	2FABPZZX4FB211001	CONCORD	11/13/86	4	BUC
FORD	TEMPO	85	.	CONCORD	11/17/86	4	BUC
FORD	THUNDERBIRD	85	1FABP46F5FH197285	CONCORD	11/12/86	8	BUC
FORD	THUNDERBIRD	85	1FARP4637GH144417	CONCORD	10/27/86	6	BUC

MAKE	MODEL	YR	FUEL	BDYSTL	TIL	ODO	TRAN	PBRAK	PSTR
AUDI	4000S	82	INJ	4DR	N	80057	AUT	?	?
AUDI	4000S	84	INJ	4DR	N	59470	MAN	Y	Y
AUDI	400S	83	INJ	4DR	N	77202	AUT	.	.
AUDI	5000	84	INJ	4DR	N	68814	MAN	Y	Y
AUDI	5000S	84	INJ	4DR	N	55825	AUT	Y	Y
AUDI	5000 TURBO	82	INJ	4DR	N	84198	AUT	Y	Y
AUDI	5000 TURBO	86	INJ	4DR	N	11509	AUT	Y	Y
BUICK	RIVERA	85	CARB	2DR	Y	35569	AUT	Y	Y
CADILLAC	COUPE DEVILL	85	INJ	2DR	Y	36731	AUT	Y	Y
CADILLAC	ELDORADO	85	INJ	2DR	Y	26208	AUT	Y	Y
CADILLAC	FLEETWOOD	85	INJ	4DR	Y	35887	AUT	Y	Y
CHEVY	CAMARO	85	INJ	2DR	Y	13898	AUT	Y	Y
CHEVY	CAMARO	85	INJ	2DR	N	21197	AUT	Y	Y
CHEVY	CAMARO	85	INJ	2DR	N	21627	MAN	Y	Y
CHEVY	CAPRICE CLAS	85	INJ	4DR	Y	69265	AUT	Y	Y
CHEVY	CAVALIER	85	INJ	4DR	N	70279	AUT	Y	Y
CHEVY	CAVALIER	85	INJ	4DR	N	10326	AUT	Y	Y
CHEVY	CAVALIER	85	INJ	WAG	N	31604	AUT	Y	Y
CHEVY	CAVALIER	85	INJ	4DR	N	47755	AUT	Y	Y
CHEVY	CELEBRITY	85	INJ	4DR	Y	30697	AUT	Y	Y
CHEVY	CELEBRITY	85	INJ	4DR	N	45488	AUT	Y	Y
CHEVY	CELEBRITY	85	CARB	4DR	N	62230	AUT	Y	Y
CHEVY	CELEBRITY	85	INJ	4DR	Y	54776	AUT	Y	Y
CHEVY	CELEBRITY	85	INJ	4DR	N	37903	AUT	Y	Y
CHEVY	MONTE CARLO	85	INJ	2DR	Y	40253	AUT	Y	Y
CHEVY	MONTE CARLO	85	INJ	2DR	Y	41478	AUT	Y	Y
CHEVY	MONTE CARLO	85	CARB	2DR	Y	19448	AUT	Y	Y
CHEVY	MONTE CARLO	85	INJ	2DR	Y	38888	AUT	Y	Y
CHEVY	NOVA	85	CARB	4DR	N	5697	AUT	Y	Y
CHEVY	CAMARO	85	INJ	2DR	N	27095	AUT	Y	Y
FORD	ESCORT	85	CARB	WAG	N	43209	AUT	N	Y
FORD	ESCORT	85	INJ	4DR	.	37090	AUT	Y	Y
FORD	ESCORT	85	CARB	2DR	N	19187	MAN	N	Y
FORD	LTD	85	INJ	4DR	Y	37740	AUT	Y	Y
FORD	LTD	85	INJ	4DR	Y	20862	AUT	Y	Y
FORD	LTD	85	INJ	4DR	Y	29537	AUT	Y	Y
FORD	LTD	85	INJ	4DR	Y	35212	AUT	Y	Y
FORD	MARK IV	85	INJ	2DR	Y	32588	AUT	Y	Y
FORD	MARK IV	85	INJ	2DR	Y	36492	AUT	Y	Y
FORD	MUSTANG	85	INJ	2DR	Y	11643	AUT	Y	Y
FORD	MUSTANG LX	85	CARB	2DR	N	7907	MAN	Y	Y
FORD	MUSTANG LX	85	CARB	2DR	Y	27121	MAN	Y	Y
FORD	TEMPO	85	CARB	4DR	N	27526	AUT	Y	Y
FORD	TEMPO	85	CARB	4DR	Y	34544	AUT	N	Y
FORD	TEMPO	85	CARB	4DR	N	2927	AUT	Y	Y
FORD	TEMPO	85	INJ	2DR	N	20981	AUT	Y	Y
FORD	THUNDERBIRD	85	INJ	2DR	Y	9988	AUT	Y	Y
FORD	THUNDERBIRD	85	INJ	2DR	Y	21841	AUT	Y	Y

MAKE	MODEL	YR	AC	CRCON	SHIFT	PV	SWT
AUDI	4000S	82	N	N	CENCON	POOR	YES
AUDI	4000S	84	Y	?	CENCON	FAIR	YES
AUDI	400S	83	Y	N	CENCON	FAIR	N
AUDI	5000	84	Y	Y	CENCON	POOR	YES
AUDI	5000S	84	Y	Y	CENCON	GOOD	LEFT
AUDI	5000 TURBO	82	Y	Y	CENCON	POOR	YES
AUDI	5000 TURBO	86	Y	N	CENCON	POOR	LEFT,1"
BUICK	RIVERA	85	Y	Y	STCOL	GOOD	N
CADILLAC	COUPE DEVILL	85	Y	Y	STCOL	FAIR	N
CADILLAC	ELDORADO	85	Y	Y	STCOL	GOOD	N
CADILLAC	FLEETWOOD	85	Y	Y	STCOL	GOOD	N
CHEVY	CAMARO	85	Y	N	CENCON	GOOD	N
CHEVY	CAMARO	85	Y	N	CENCON	FAIR	N
CHEVY	CAMARO	85	N	N	CENCON	FAIR	N
CHEVY	CAPRICE CLAS	85	Y	N	STCOL	GOOD	YES
CHEVY	CAVALIER	85	Y	N	CENCON	FAIR	LEFT,26/32
CHEVY	CAVALIER	85	Y	N	CENCON	FAIR	N
CHEVY	CAVALIER	85	Y	N	CENCON	FAIR	LEFT 1+4/32
CHEVY	CAVALIER	85	Y	N	CENCON	FAIR	LEFT,15/32
CHEVY	CELEBRITY	85	Y	N	STCOL	UNK	N
CHEVY	CELEBRITY	85	Y	N	STCOL	GOOD	LEFT 16/32
CHEVY	CELEBRITY	85	Y	N	STCOL	GOOD	N
CHEVY	CELEBRITY	85	Y	N	STCOL	GOOD	N
CHEVY	CELEBRITY	85	Y	N	STCOL	GOOD	N
CHEVY	MONTE CARLO	85	Y	N	STCOL	FAIR	N
CHEVY	MONTE CARLO	85	Y	Y	STCOL	GOOD	N
CHEVY	MONTE CARLO	85	Y	Y	CENCON	FAIR	N
CHEVY	MONTE CARLO	85	Y	Y	STCOL	EXCELLENT	LEFT 27/32
CHEVY	NOVA	85	N	N	CENCON	GOOD	N
CHEVY	CAMARO	85	Y	N	CENCON	GOOD	LEFT 18/32
FORD	ESCORT	85	N	N	CENCON	POOR	N
FORD	ESCORT	85	N	N	CENCON	POOR	LEFT 21/32
FORD	ESCORT	85	N	N	CENCON	FAIR	N
FORD	LTD	85	Y	Y	STCOL	GOOD	N
FORD	LTD	85	Y	Y	STCOL	GOOD	N
FORD	LTD	85	Y	Y	STCOL	GOOD	N
FORD	LTD	85	Y	Y	STCOL	GOOD	N
FORD	MARK IV	85	Y	Y	CENCON	FAIR	N
FORD	MARK IV	85	N	Y	CENCON	FAIR	N
FORD	MUSTANG	85	Y	Y	CENCON	GOOD	LEFT 29/32
FORD	MUSTANG LX	85	N	Y	CENCON	GOOD	N
FORD	MUSTANG LX	85	Y	Y	CENCON	FAIR	YES
FORD	TEMPO	85	Y	N	CENCON	POOR	YES
FORD	TEMPO	85	Y	Y	CENCON	POOR	N
FORD	TEMPO	85	Y	N	CENCON	FAIR	N
FORD	TEMPO	85	Y	N	CENCON	POOR	LEFT,1+5/32
FORD	THUNDERBIRD	85	Y	Y	STCOL	GOOD	N
FORD	THUNDERBIRD	85	Y	Y	STCOL	FAIR	N

MAKE	MODEL	YR	SOF	C1T	C1M	C1B	E2	F3
AUDI	4000S	82	N	1.84	1.84	1.84	3.69	2.09
AUDI	4000S	84	N	1.84	1.84	1.84	4.19	2.59
AUDI	400S	83	N	1.81	1.81	1.81	3.09	2.09
AUDI	5000	84	N	2.00	2.00	2.00	3.62	3.00
AUDI	5000S	84	N	2.06	2.06	2.06	4.12	2.69
AUDI	5000 TURBO	82	N	2.00	2.03	1.28	3.25	2.56
AUDI	5000 TURBO	86	LEFT	2.00	2.12	2.00	4.00	2.66
BUICK	RIVERA	85	N	1.94	2.50	2.84	7.47	2.59
CADILLAC	COUPE DEVILL	85	N	1.81	2.06	2.22	5.00	2.06
CADILLAC	ELDORADO	85	N	2.00	2.50	2.87	7.50	2.56
CADILLAC	FLEETWOOD	85	N	1.87	2.12	2.25	4.97	2.00
CHEVY	CAMARO	85	N	1.37	1.97	1.37	5.34	2.34
CHEVY	CAMARO	85	N	2.00	1.94	1.56	5.37	2.37
CHEVY	CAMARO	85	N	1.66	1.94	1.53	5.31	2.41
CHEVY	CAPRICE CLAS	85	N	2.31	2.50	2.72	6.25	2.37
CHEVY	CAVALIER	85	N	1.78	2.00	2.12	4.88	2.37
CHEVY	CAVALIER	85	LEFT	1.78	1.97	2.12	4.94	1.87
CHEVY	CAVALIER	85	YES,TO LEFT	1.75	2.00	2.19	4.97	1.78
CHEVY	CAVALIER	85	LEFT	1.69	2.00	2.75	4.91	2.25
CHEVY	CELEBRITY	85	N	2.12	2.53	2.72	5.19	2.31
CHEVY	CELEBRITY	85	N	2.19	2.50	2.72	5.16	2.28
CHEVY	CELEBRITY	85	N	2.22	2.75	2.50	5.25	2.31
CHEVY	CELEBRITY	85	N	2.25	2.53	2.69	5.19	2.31
CHEVY	CELEBRITY	85	N	2.19	2.50	2.72	5.12	2.31
CHEVY	MONTE CARLO	85	N	1.62	1.97	2.12	5.25	2.37
CHEVY	MONTE CARLO	85	N	1.66	1.94	2.09	5.28	2.28
CHEVY	MONTE CARLO	85	N	1.72	1.91	2.16	5.31	2.47
CHEVY	MONTE CARLO	85	N	1.69	1.91	2.12	5.37	2.37
CHEVY	NOVA	85	N	1.16	1.72	1.16	3.75	2.06
CHEVY	CAMARO	85	N	1.59	1.94	1.56	5.37	2.37
FORD	ESCORT	85	LEFT	1.47	1.47	1.47	3.37	1.94
FORD	ESCORT	85	N	1.50	1.50	1.50	3.37	1.94
FORD	ESCORT	85	N	1.37	1.37	1.37	3.37	1.91
FORD	LTD	85	N	1.19	1.19	1.09	5.25	2.50
FORD	LTD	85	N	1.16	1.16	1.09	5.28	2.53
FORD	LTD	85	N	1.19	1.19	1.06	5.28	2.44
FORD	LTD	85	N	1.19	1.19	1.06	5.28	2.44
FORD	MARK IV	85	YES	1.75	1.75	1.75	5.28	2.62
FORD	MARK IV	85	N	1.75	1.75	1.75	5.34	2.47
FORD	MUSTANG	85	N	1.12	1.12	1.00	5.28	1.91
FORD	MUSTANG LX	85	N	1.22	1.09	1.22	5.28	2.00
FORD	MUSTANG LX	85	N	1.09	1.09	1.00	5.31	2.00
FORD	TEMPO	85	N	1.44	1.44	1.56	3.44	1.94
FORD	TEMPO	85	YES	1.47	1.47	1.50	3.41	1.91
FORD	TEMPO	85	YES	1.44	1.44	1.50	3.37	1.91
FORD	TEMPO	85	LEFT	1.47	1.47	1.50	3.44	1.91
FORD	THUNDERBIRD	85	N	1.19	1.19	1.06	5.37	2.50
FORD	THUNDERBIRD	85	N	1.16	1.16	1.00	5.22	2.59

MAKE	MODEL	YR	X4T	X4M	X4B	X5	X6	B7	X8	D1	D2
AUDI	4000S	82	3.16	3.16	3.00	6.75	4.62	1.72	19.00	1.94	1.75
AUDI	4000S	84	2.12	2.12	1.56	5.50	3.50	2.09	22.50	1.37	1.28
AUDI	400S	83	3.12	3.12	2.78	6.56	4.75	1.84	19.25	2.12	2.19
AUDI	5000	84	2.28	2.37	1.69	6.25	4.62	2.56	22.75	1.84	1.69
AUDI	5000S	84	3.87	3.87	2.87	6.25	4.12	2.19	20.00	2.12	2.00
AUDI	5000 TURBO	82	3.94			6.62	5.47	3.37	18.25	0.91	1.19
AUDI	5000 TURBO	86	3.81	3.94	2.87	6.00	4.34	2.56	19.50	2.44	2.19
BUICK	RIVERA	85	7.37	6.62	6.00	5.69	1.09	2.66	23.50	3.75	3.41
CADILLAC	COUPE DEVILL	85	5.28	5.09	4.62	6.22	2.94	2.50	22.50		
CADILLAC	ELDORADO	85	7.25	7.66	6.00	6.00	0.50	2.25	24.00	4.88	5.25
CADILLAC	FLEETWOOD	85	5.34	5.06	4.62	5.62	3.00	2.87	23.00		
CHEVY	CAMARO	85	5.75	5.41	4.81	4.50	2.37	2.25	20.25	3.37	1.62
CHEVY	CAMARO	85	5.75	5.44	5.00	5.25	2.22	2.50	20.00	2.72	1.31
CHEVY	CAMARO	85	3.47	3.09	2.50	4.88	2.16	2.81	20.00	2.53	1.75
CHEVY	CAPRICE CLAS	85	5.75	5.44	5.00	6.50	2.78	3.00	22.50	2.56	2.50
CHEVY	CAVALIER	85	4.34	4.00	3.59	5.56	3.00	2.37	21.25		
CHEVY	CAVALIER	85	3.87	3.75	3.31	6.00	3.00	2.75	22.00		
CHEVY	CAVALIER	85	3.75	3.47	3.12	5.50	2.87	2.62	22.00		
CHEVY	CAVALIER	85	4.34	4.06	3.97	5.37	3.00	1.78	22.00		
CHEVY	CELEBRITY	85	5.62	5.34	4.97	6.37	4.25	2.53	23.00		
CHEVY	CELEBRITY	85	5.69	5.37	4.91	6.00	3.56	2.84	23.00		
CHEVY	CELEBRITY	85	5.66	4.91	5.31	6.00	3.25	2.44	22.00		
CHEVY	CELEBRITY	85	5.78	5.37	4.97	5.91	4.00	2.81	22.00		
CHEVY	CELEBRITY	85	5.75	5.41	4.94	6.12	3.75	2.62	22.50		
CHEVY	MONTE CARLO	85	4.34	4.12	3.50	6.44	2.37	2.25	19.00	2.37	2.25
CHEVY	MONTE CARLO	85	4.31	4.03	3.53	5.94	2.09	1.75	18.25	2.19	2.12
CHEVY	MONTE CARLO	85	4.37	4.09	3.66	6.50	2.41	2.12	18.75	2.00	2.19
CHEVY	MONTE CARLO	85	4.28	4.00	3.62	6.00	1.87	1.66	18.75	2.75	2.41
CHEVY	NOVA	85	3.75	4.03	3.62	5.72	3.37	2.37	20.50	2.41	2.34
CHEVY	CAMARO	85	5.72	5.41	5.00	5.00	2.62	1.81	20.00	2.41	1.62
FORD	ESCORT	85	3.50	3.22	2.78	6.75	4.06	3.62	20.50		
FORD	ESCORT	85	3.47	3.19	2.66	6.62	4.03	3.12	21.50		
FORD	ESCORT	85	2.25	2.16	1.66	6.37	3.94	3.72	20.75		
FORD	LTD	85	3.94	3.66	3.00	5.00	2.25	2.91	18.00	0.91	1.53
FORD	LTD	85	4.00	3.66	3.25	5.31	2.37	3.72	18.25	1.09	1.16
FORD	LTD	85	3.91	3.72	3.00	5.53	2.28	3.34	17.50	1.12	1.31
FORD	LTD	85	4.00	3.75	3.00	5.12	2.25	2.78	17.75	1.09	1.62
FORD	MARK IV	85	4.03	3.72	3.16	5.00	1.91	2.69	16.75	1.03	1.22
FORD	MARK IV	85	4.06	3.72	3.00	4.75	2.12	2.59	16.75	0.84	1.00
FORD	MUSTANG	85	3.25	2.94	2.37	5.37	2.62	3.25	18.00	1.28	1.75
FORD	MUSTANG LX	85	2.28	1.91	2.19	5.66	2.37	2.75	18.00	1.25	1.78
FORD	MUSTANG LX	85	2.31	2.19	1.94	5.31	2.31	2.87	17.75	0.94	1.62
FORD	TEMPO	85	3.47	3.16	2.62	6.00	3.78	3.75	20.25		
FORD	TEMPO	85	3.41	3.25	2.75	5.72	3.69	3.28	18.75		
FORD	TEMPO	85	3.47	3.19	2.62	5.62	3.94	3.00	20.00		
FORD	TEMPO	85	3.37	3.25	2.50	5.87	3.75	3.16	20.00		
FORD	THUNDERBIRD	85	4.00	3.72	3.00	5.12	1.94	2.94	18.25	1.34	1.25
FORD	THUNDERBIRD	85	4.03	3.69	3.00	5.09	2.25	2.81	18.00	1.16	0.91

MAKE	MODEL	YR	D3	X12	A13	X14	X15	X16	G1
AUDI	4000S	82	1.56	0.69	0.12	10.19	22.75	.	2.00
AUDI	4000S	84	0.94	0.37	2.81	10.41	23.25	.	2.25
AUDI	400S	83	1.94	1.37	0.62	10.37	23.00	.	2.00
AUDI	5000	84	1.66	1.34	2.87	12.00	22.00	.	1.53
AUDI	5000S	84	1.50	1.37	0.00	11.00	23.66	.	2.25
AUDI	5000 TURBO	82	1.19	0.19	0.62	10.28	23.00	.	2.06
AUDI	5000 TURBO	86	1.34	1.34	1.34	10.44	23.75	.	1.59
BUICK	RIVERA	85	2.16	0.62	2.50	12.06	25.50	.	2.87
CADILLAC	COUPE DEVILL	85		0.19	2.50	9.37	25.94	.	3.41
CADILLAC	ELDORADO	85	2.75	0.59	3.00	11.19	25.25	.	2.87
CADILLAC	FLEETWOOD	85		0.00	2.53	9.00	26.25	.	3.00
CHEVY	CAMARO	85	1.62	0.12	0.12	9.47	26.69	.	2.69
CHEVY	CAMARO	85	1.12	0.16	1.87	9.00	26.00	.	2.50
CHEVY	CAMARO	85	1.62	0.25	0.94	8.47	25.75	.	2.25
CHEVY	CAPRICE CLAS	85	2.25	2.91	2.00	11.31	20.00	.	2.87
CHEVY	CAVALIER	85		1.47	2.47	11.62	24.25	.	3.47
CHEVY	CAVALIER	85		1.12	1.50	11.56	24.25	.	2.56
CHEVY	CAVALIER	85		1.31	3.50	11.62	24.44	.	2.12
CHEVY	CAVALIER	85		1.25	2.81	10.66	24.75	.	2.91
CHEVY	CELEBRITY	85		0.87	3.75	11.06	25.50	.	2.37
CHEVY	CELEBRITY	85		0.75	3.50	10.50	25.12	.	2.87
CHEVY	CELEBRITY	85	2.87	0.37	5.16	10.78	26.37	.	2.75
CHEVY	CELEBRITY	85		0.00	3.78	11.59	27.25	.	2.28
CHEVY	CELEBRITY	85		0.25	4.72	11.25	24.69	.	2.12
CHEVY	MONTE CARLO	85	1.87	0.00	1.25	11.50	26.87	.	2.81
CHEVY	MONTE CARLO	85	2.19	0.19	0.19	10.53	26.25	.	3.25
CHEVY	MONTE CARLO	85	1.94	1.00	0.69	12.00	26.25	.	3.00
CHEVY	MONTE CARLO	85	2.03	0.75	0.75	10.12	26.56	.	3.06
CHEVY	NOVA	85	2.37	0.37	4.25	12.62	23.50	.	1.87
CHEVY	CAMARO	85	1.53	0.78	1.00	7.87	26.94	.	2.25
FORD	ESCORT	85		0.22	2.22	10.75	24.50	.	3.00
FORD	ESCORT	85		0.62	2.12	10.78	24.75	.	2.81
FORD	ESCORT	85		0.19	3.97	10.50	25.00	.	4.62
FORD	LTD	85	1.62	0.87	1.03	10.00	25.75	.	2.91
FORD	LTD	85	1.19	1.03	0.25	9.75	25.12	.	2.50
FORD	LTD	85	1.59	0.81	0.31	10.00	27.75	.	3.00
FORD	LTD	85	1.62	0.91	0.87	9.62	24.75	.	2.62
FORD	MARK IV	85	1.22	0.75	2.47	10.00	25.25	.	4.12
FORD	MARK IV	85	1.09	0.41	0.09	10.44	25.87	.	3.22
FORD	MUSTANG	85	1.69	0.62	0.75	10.44	25.87	.	2.66
FORD	MUSTANG LX	85	1.69	0.75	0.75	10.75	25.75	.	3.00
FORD	MUSTANG LX	85	1.53	0.56	1.28	10.00	23.25	.	2.66
FORD	TEMPO	85		0.28	2.91	23.84	11.37	.	3.00
FORD	TEMPO	85	2.91	0.19	2.84	10.87	25.34	.	2.81
FORD	TEMPO	85		0.12	3.50	11.87	24.47	.	2.12
FORD	TEMPO	85		0.50	4.12	11.87	24.62	.	2.59
FORD	THUNDERBIRD	85	1.25	1.12	0.25	10.50	25.81	.	2.22
FORD	THUNDERBIRD	85	0.81	0.59	2.22	26.37	11.19	.	3.16

MAKE	MODEL	YR	G2	G3	
AUDI	4000S	82	0.44	1.41	Y
AUDI	4000S	84	0.56	2.59	Y
AUDI	400S	83	1.25	2.19	Y
AUDI	5000	84	1.03	2.12	Y
AUDI	5000S	84	0.66	1.87	Y
AUDI	5000 TURBO	82	1.16	2.31	Y
AUDI	5000 TURBO	86	0.72	1.84	.
BUICK	RIVERA	85	1.50	2.78	Y
CADILLAC	COUPE DEVILL	85	1.69	2.66	Y
CADILLAC	ELDORADO	85	2.00	2.87	Y
CADILLAC	FLEETWOOD	85	1.59	1.94	Y
CHEVY	CAMARO	85	0.62	2.09	Y
CHEVY	CAMARO	85	1.00	2.09	Y
CHEVY	CAMARO	85	0.75	2.50	Y
CHEVY	CAPRICE CLAS	85	0.34	1.03	Y
CHEVY	CAVALIER	85	1.69	2.62	Y
CHEVY	CAVALIER	85	1.53	2.34	Y
CHEVY	CAVALIER	85	1.87	2.87	Y
CHEVY	CAVALIER	85	1.87	2.75	Y
CHEVY	CELEBRITY	85	1.91	2.94	Y
CHEVY	CELEBRITY	85	1.62	2.69	Y
CHEVY	CELEBRITY	85	1.62	2.91	Y
CHEVY	CELEBRITY	85	0.25	1.06	Y
CHEVY	CELEBRITY	85	1.56	3.00	Y
CHEVY	MONTE CARLO	85	1.12	2.25	Y
CHEVY	MONTE CARLO	85	1.37	2.31	Y
CHEVY	MONTE CARLO	85	1.59	2.25	.
CHEVY	MONTE CARLO	85	1.37	2.37	Y
CHEVY	NOVA	85	1.37	2.00	.
CHEVY	CAMARO	85	0.75	0.75	Y
FORD	ESCORT	85	1.56	2.37	Y
FORD	ESCORT	85	1.37	2.12	Y
FORD	ESCORT	85	1.37	2.12	Y
FORD	LTD	85	1.00	1.91	Y
FORD	LTD	85	1.12	2.50	Y
FORD	LTD	85	1.31	2.12	Y
FORD	LTD	85	1.00	2.25	Y
FORD	MARK IV	85	0.91	1.81	Y
FORD	MARK IV	85	0.94	1.78	Y
FORD	MUSTANG	85	1.12	2.12	Y
FORD	MUSTANG LX	85	1.00	1.62	Y
FORD	MUSTANG LX	85	1.25	1.91	Y
FORD	TEMPO	85	0.62	1.25	Y
FORD	TEMPO	85	1.28	2.31	Y
FORD	TEMPO	85	1.00	1.87	Y
FORD	TEMPO	85	1.00	1.81	Y
FORD	THUNDERBIRD	85	0.87	2.12	Y
FORD	THUNDERBIRD	85	1.06	2.53	Y

MAKE	MODEL	YR	VINNO	LOCATION	DATE	CYL	SEAT
LINCOLN	CONTINENTAL	85	1MRBP97F2F4743706	CONCORD	11/3/86	8	BUC
LINCOLN	CONTINENTAL	85	1MRBP97F3F4743715	CONCORD	10/27/86		BUC
NISSAN	300ZX		JNIHZ1453FX088040	CONCORD	.	6	BUC
NISSAN	300ZX	85	JNIHZ1655FX042013	CONCORD	10/15/86	6	BUC
NISSAN	300ZX TURBO	85	JNICZ1453FX064329	CONCORD	12/16/86	6	BUC
NISSAN	MAXIMA	85	JNIHUIIS2FT006485	CONCORD	11/24/86	6	BUC
OLDS	98	85	1G3CW6938F4310573	CONCORD	11/26/86	6	BUC
OLDS	98	85	1G3CW6931F4314978	CONCORD	11/26/86	6	BUC
OLDS	98	85	1G3CW693XF4325963	CONCORD	11/5/86	6	BUC
OLDS	98	85	1G3CW693XF4325963	CONCORD	.	6	BUC
OLDS	CUTLASS SUP.	85	1G3GR69A7FR388125	CONCORD	12/1/86	6	BEN
OLDS	CUTLAS SUPRE	85	2636M47AIF2326194	CONCORD	12/16/86	6	BUC
PONTIAC	FIERO	85	162PF3793FP230588	CONCORD	11/25/86	6	BUC
PONTIAC	FIERO	85	.	CONCORD	11/10/86	6	BUC
PONTIAC	FIERO	85	1G2PM37R4FP247387	CONCORD	.	4	BUC
TOYOTA	CELICA ST	85	JT2RA63C7F6236995	CONCORD	10/14/86	4	BUC

MAKE	MODEL	YR	FUEL	BDYSTL	TIL	ODO	TRAN	PBRAK	PSTR
LINCOLN	CONTINENTAL	85	INJ	4DR	Y	34924	AUT	Y	Y
LINCOLN	CONTINENTAL	85	INJ	4DR	Y		AUT	Y	Y
NISSAN	300ZX		INJ	2DR	N	23848	MAN	Y	Y
NISSAN	300ZX	85	INJ	2DR	Y	16515	AUT	Y	Y
NISSAN	300ZX TURBO	85	INJ	2DR	Y	17522	AUT	Y	Y
NISSAN	MAXIMA	85	INJ	4DR	Y	26959	AUT	Y	Y
OLDS	98	85	INJ	4DR	Y	39318	AUT	Y	Y
OLDS	98	85	INJ	4DR	Y	33727	AUT	.	Y
OLDS	98	85	INJ	4DR	Y	67018	AUT	Y	Y
OLDS	98	85	INJ	4DR	Y	67018	AUT	Y	Y
OLDS	CUTLASS SUP.	85	CARB	4DR	N	37449	AUT	Y	Y
OLDS	CUTLAS SUPRE	85	CARB	2DR	Y	24511	AUT	Y	Y
PONTIAC	FIERO	85	INJ	2DR	Y	26169	AUT	Y	N
PONTIAC	FIERO	85	INJ	2DR	Y	11521	MAN	Y	N
PONTIAC	FIERO	85	INJ	2DR	N	18188	MAN	Y	N
TOYOTA	CELICA ST	85	INJ	2DR	N	25015	MAN	Y	Y

MAKE	MODEL	YR	AC	CRCON	SHIFT	PV	SWT
LINCOLN	CONTINENTAL	85	N	Y	STCOL	FAIR	N
LINCOLN	CONTINENTAL	85	Y	Y	STCOL	FAIR	YES
NISSAN	300ZX		Y	Y	CENCON	FAIR	LEFT 21/32
NISSAN	300ZX	85	Y	Y	CENCON	POOR	N
NISSAN	300ZX TURBO	85	Y	Y	CENCON	GOOD	N
NISSAN	MAXIMA	85	Y	Y	CENCON	GOOD	LEFT 27/32
OLDS	98	85	Y	Y	STCOL	GOOD	N
OLDS	98	85	Y	Y	STCOL	GOOD	N
OLDS	98	85	Y	Y	STCOL	FAIR	N
OLDS	98	85	Y	Y	STCOL	FAIR	N
OLDS	CUTLASS SUP.	85	Y	N	STCOL	GOOD	LEFT 8/32
OLDS	CUTLAS SUPRE	85	Y	Y	STCOL	GOOD	N
PONTIAC	FIERO	85	N	N	CENCON	POOR	LEFT 30/32
PONTIAC	FIERO	85	Y	Y	CENCON	FAIR	N
PONTIAC	FIERO	85	N	N	CENCON	FAIR	N
TOYOTA	CELICA ST	85	Y	N	CENCON	FAIR	N

MAKE	MODEL	YR	SOF	C1T	C1M	C1B	E2	F3
LINCOLN	CONTINENTAL	85	N	1.72	1.72	1.72	5.34	2.59
LINCOLN	CONTINENTAL	85	YES	1.75	1.75	1.75	5.22	2.59
NISSAN	300ZX		YES,TO LEFT	1.87	1.97	1.91	5.84	2.16
NISSAN	300ZX	85	N	1.94	1.94	1.94	5.91	2.31
NISSAN	300ZX TURBO	85	N	1.91	1.94	1.87	5.91	2.25
NISSAN	MAXIMA	85	YES	1.37	2.22	1.87	5.91	2.31
OLDS	98	85	N	1.81	2.09	2.22	4.91	2.00
OLDS	98	85	N	1.81	2.09	2.25	4.88	2.00
OLDS	98	85	N	1.81	2.03	2.22	5.03	2.06
OLDS	98	85	N	1.78	2.09	2.22	5.00	2.00
OLDS	CUTLASS SUP.	85	N	1.69	2.00	2.09	5.28	2.34
OLDS	CUTLAS SUPRE	85	N	1.62	1.91	2.09	5.34	2.37
PONTIAC	FIERO	85	YES,TO RIGHT	1.94	2.12	2.28	4.94	2.37
PONTIAC	FIERO	85	RIGHT	1.94	2.12	2.25	5.00	2.25
PONTIAC	FIERO	85	RIGHT	1.91	2.12	2.25	4.88	2.34
TOYOTA	CELICA ST	85	N	1.72	1.72	1.72	4.25	2.41

MAKE	MODEL	YR	X4T	X4M	X4B	X5	X6	B7	X8	D1	D2
LINCOLN	CONTINENTAL	85	4.06	3.78	3.00	4.75	1.75	2.37	17.25	0.81	0.94
LINCOLN	CONTINENTAL	85	4.09	3.75	3.22	4.81	1.69	2.75	17.25	1.00	1.25
NISSAN	300ZX		2.66	2.56	1.87	6.00	3.47	1.87	18.75	1.78	1.66
NISSAN	300ZX	85	4.41	4.06	3.41	6.31	2.25	2.62	18.25	1.34	1.56
NISSAN	300ZX TURBO	85	4.44	4.00	3.25	6.12	3.56	2.62	18.50	1.87	2.00
NISSAN	MAXIMA	85	5.62	4.88	5.56	5.62	4.19	2.12	20.50	1.59	1.59
OLDS	98	85	5.28	5.06	4.62	6.87	2.75	2.50	23.00		
OLDS	98	85	5.28	5.09	4.62	6.81	3.34	2.78	23.00		
OLDS	98	85	5.28	5.09	4.72	6.00	4.16	2.94	23.00		
OLDS	98	85	5.34	5.09	4.59	6.34	4.00	2.66	23.25		
OLDS	CUTLASS SUP.	85	4.31	4.09	3.72	6.00	2.81	2.19	19.25	1.81	2.00
OLDS	CUTLAS SUPRE	85	4.34	4.09	3.50	6.34	2.25	2.31	18.50	2.19	1.75
PONTIAC	FIERO	85	4.25	4.00	3.94	5.50	3.25	3.12	22.50	1.37	0.75
PONTIAC	FIERO	85	2.37	2.12	1.72	5.75	3.50	2.12	15.50	1.53	1.06
PONTIAC	FIERO	85	2.37	2.09	1.62	5.47	3.28	2.19	22.75	1.50	0.91
TOYOTA	CELICA ST	85	2.25	2.16	1.69	5.81	3.72	2.62	18.25	2.53	1.53

MAKE	MODEL	YR	D3	X12	A13	X14	X15	X16	G1
LINCOLN	CONTINENTAL	85	0.62	0.75	0.41	10.81	25.75	.	3.50
LINCOLN	CONTINENTAL	85	1.25	1.72	0.81	24.75	11.94	.	3.59
NISSAN	300ZX		1.00	0.00	1.87	10.25	25.00	.	1.62
NISSAN	300ZX	85	1.28	0.00	0.00	9.87	23.50	.	1.81
NISSAN	300ZX TURBO	85	1.66	0.00	0.00	10.19	25.12	BULGE	2.03
NISSAN	MAXIMA	85	1.59	0.25	4.84	9.25	23.00	.	1.91
OLDS	98	85		0.56	3.50	10.50	26.00	.	3.00
OLDS	98	85		0.56	3.25	10.41	25.50	.	2.75
OLDS	98	85		0.37	3.00	9.87	24.75	.	2.25
OLDS	98	85		0.62	2.81	10.06	24.72	.	2.25
OLDS	CUTLASS SUP.	85	2.03	0.44	0.66	10.25	25.87	.	2.75
OLDS	CUTLAS SUPRE	85	1.62	1.12	0.62	9.91	26.50	.	2.75
PONTIAC	FIERO	85	0.84	0.00	6.50	7.31	0.00	BULGE	1.37
PONTIAC	FIERO	85	1.12	0.34	6.25	8.00	25.50	BULGE	1.84
PONTIAC	FIERO	85	0.84	0.00	6.50	7.50	25.25	BULGE	2.00
TOYOTA	CELICA ST	85	1.16	0.25	2.34	8.87	24.72	.	2.28

MAKE	MODEL	YR	G2	G3	
LINCOLN	CONTINENTAL	85	0.87	2.00	Y
LINCOLN	CONTINENTAL	85	1.12	2.12	N
NISSAN	300ZX		0.50	1.25	Y
NISSAN	300ZX	85	0.94	1.91	Y
NISSAN	300ZX_TURBO	85	0.62	2.62	Y
NISSAN	MAXIMA	85	1.25	2.00	Y
OLDS	98	85	1.75	2.62	Y
OLDS	98	85	1.59	2.72	Y
OLDS	98	85	1.62	2.50	Y
OLDS	98	85	1.47	2.37	Y
OLDS	CUTLASS_SUP.	85	1.87	2.50	Y
OLDS	CUTLAS_SUPRE	85	1.25	2.25	Y
PONTIAC	FIERO	85	1.37	2.25	Y
PONTIAC	FIERO	85	1.19	1.78	Y
PONTIAC	FIERO	85	1.50	2.06	Y
TOYOTA	CELICA_ST	85	1.00	1.81	Y

REFERENCES

1. Bentley, R. Audi 5000's Official Factory Repair Manual 1984, 1985, Robert Bentley, Inc. Cambridge, Mass., 1985

2. Audi 5000's Official Factory Repair Manual 1977- 1983, Robert Bentley, Inc., Cambridge, Mass., 1983

3. Chapanis, A., J.S. Cook III, M.W. Lund, and C.T. Morgan. Human Engineering guide to Equipment Design, McGraw-Hill, New York, NY, 1963.

4. Volkswagen of America. CIS-Electronic Fuel Injection, 2d ed., Audi of America Service Training, (Volkswagen of America Service Publications, Troy MI) #wsp 521-142-00 undated.

5. Hoxie, P. "Assessment Of Driver Inexperience With An Automobile As a Factor Which Contributes To Highway Accidents," DOT-HS-806-593, December 1984.

6. Perel, M. "Vehicle Familiarity and Safety" DOT-HS-806-509, July 1983

7. Rogers, S.B., W.W. Wierwille,, "The Occurrence of Accelerator and Brake Pedal Actuation Errors During Simulated Driving," Vehicle Analysis and Simulation Laboratory, Virginia Polytechnic Institute and State University, 1988

8. SAE Recommended Practice J1100,. Motor Vehicle Dimensions, Motor Vehicle Dimensions, SAE Recommended Practice J1100, Revised June 1984. Society of Automotive Engineers Handbook, 1986.

9. SAE Recommended Practice J826b, Devices for Use in Defining and Measuring Vehicle Seating Accomodations, SAE Standard J826, Revised April 1980. Society of Automotive Engineers Handbook, 1986.

10. Taylor, C.F. 1966. The Internal Combustion Engine in Theory and Practice, Vol. I Massachusetts Institute of Technology Press, Cambridge, Mass., 1966.