

PIRG

DOT HS 800 624

AN ASSESSMENT OF AUTOMOTIVE FUEL SYSTEM FIRE HAZARDS

**Dynamic Science
A Division of Marshall Industries
1800 West Deer Valley Drive
Phoenix, Arizona 85027**

**Contract No. DOT FH 11 7579
December 1971
Final Report**

**PREPARED FOR:
U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
WASHINGTON, D.C. 20590**

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. DOT/HS-800 624		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle AN ASSESSMENT OF AUTOMOTIVE FUEL SYSTEM FIRE HAZARDS				5. Report Date December 1971	
				6. Performing Orgn Code	
7. Author(s) Neva B. Johnson				8. Performing Orgn Rpt No. 2310/20-71-44	
9. Performing Organization Name and Address Dynammic Science A Division of Marshall Industries 1800 West Deer Valley Drive Phoenix, Arizona 85027				10. Work Unit No.	
				11. Contract or Grant No. DOT FH-11-7579	
12. Sponsoring Agency Name and Address U. S. Department of Transportation National Highway Traffic Safety Administration Washington, D. C. 20590				13. Type of Report and Period Covered Final Report Jun 1970 - Nov 1971	
				14. Sponsoring Agency Code	
15. Supplementary Notes Report summarized in Dynamic Science Report 2310/20-71-45.					
16. Abstract An integrated program of vehicle analyses, fuel system component tests, and full-scale vehicle tests was conducted to determine automotive fuel system fire hazards in vehicles containing fuel evaporative emission control devices. Although many of the evaporative emission control systems are rather complex, most of the designs do not contribute to an increased fire hazard as long as system integrity is maintained. However, maintainability problems can be foreseen which would destroy the system integrity. The systems may also be damaged during a collision. Loss of system integrity could lead to fuel spillage and an increasing fire hazard. Fuel system damage may occur during front, rear, or side impacts, resulting in massive fuel spillage. Roll-over accidents invariably spill fuel from the carburetor and may spill fuel from components damaged during a prior collision. Rear-mounted fuel tanks are particularly susceptible to damage during rear end impacts. Any spilled fuel should be considered a fire hazard since ignition sources are likely to exist during an accident. Based on the results of this study, crashworthy fuel system modifications were recommended and performance standards for fuel system integrity were proposed.					
17. Key Words Automotive Fuel Systems Post-Crash Fire Hazards Evaporative Control Systems Crashworthy Fuel Systems				18. Distribution Statement Availability is unlimited. Document may be released to the Clearinghouse for Federal Scientific and Technical Information, Springfield, Va. 22151, for sale to the public.	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. Pages 282	
				22. Price	

TABLE OF CONTENTS

	<u>Page</u>
LIST OF ILLUSTRATIONS	v
LIST OF TABLES	xv
1. INTRODUCTION	1-1
2. BACKGROUND	2-1
2.1 ACCIDENT STATISTICS	2-1
2.1.1 Fire Accidents	2-1
2.1.2 Fuel System Damage	2-4
2.1.3 Summary.	2-6
2.2 FUEL SYSTEM STUDIES	2-6
2.3 IGNITION SOURCE STUDIES	2-8
2.4 LIMITATIONS OF PREVIOUS STUDIES	2-9
3. APPROACH	3-1
3.1 GENERAL	3-1
3.2 NEW VEHICLE ANALYSES.	3-1
3.3 CRASHED VEHICLE ANALYSES.	3-3
3.4 TESTING	3-3
3.4.1 Extreme Temperature Tests.	3-3
3.4.2 Attitude Tests	3-5
3.4.3 Component Tests.	3-5
3.4.4 Rear-End Barrier Crashes	3-6
4. FUEL SYSTEM DESIGNS.	4-1
4.1 GENERAL	4-1
4.2 FORD MOTOR COMPANY.	4-2
4.2.1 1970 Passenger Cars.	4-2
4.2.2 1971 Passenger Cars.	4-9
4.2.3 1970 One-Half-Ton Pickup Trucks.	4-12
4.2.4 1971 One-Half-Ton Pickup Trucks.	4-15

TABLE OF CONTENTS (CONTD)

	<u>Page</u>
4.3 GENERAL MOTORS CORPORATION.	4-15
4.3.1 1970 Passenger Cars.	4-15
4.3.2 1971 Passenger Cars.	4-25
4.3.3 1971 Pickup Trucks	4-31
4.4 CHRYSLER CORPORATION.	4-33
4.4.1 1970 Passenger Cars.	4-33
4.4.2 1971 Passenger Cars.	4-34
4.4.3 1971 Plymouth Cricket.	4-36
4.4.4 1971 Dodge Colt.	4-38
4.5 AMERICAN MOTORS CORPORATION	4-39
4.5.1 1970 Passenger Cars.	4-39
4.5.2 1971 Passenger Cars.	4-40
4.6 VOLKSWAGEN.	4-41
4.6.1 1970 Passenger Cars.	4-41
4.6.2 1970 Microbus.	4-44
4.6.3 1971 Passenger Cars.	4-45
4.7 TOYOTA MOTOR COMPANY.	4-46
4.7.1 1970 Passenger Cars.	4-46
4.7.2 1971 Passenger Cars.	4-48
5. FUEL SYSTEM FIRE HAZARDS	5-1
5.1 GENERAL	5-1
5.2 OPERATIONAL CONDITIONS.	5-1
5.2.1 High Environmental Temperatures.	5-1
5.2.2 Multiple Diurnal Soaks	5-7
5.2.3 Extreme Vehicle Attitudes.	5-8
5.2.4 Severe Maneuvering Forces.	5-10
5.2.5 Environmental Degradation.	5-11
5.2.6 Vibration.	5-15
5.2.7 Foreign Object Damage.	5-19
5.2.8 Component Malfunction.	5-22
5.2.9 Maintenance Errors and Omissions	5-23

TABLE OF CONTENTS (CONTD)

	<u>Page</u>
5.3 CRASH CONDITIONS.	5-26
5.3.1 Front Impacts.	5-26
5.3.2 Rear Impacts	5-41
5.3.3 Side Impacts	5-66
5.3.4 Roll-Over Accidents.	5-69
5.4 SUMMARY AND CONCLUSIONS	5-79
5.4.1 Operating Conditions	5-79
5.4.2 Crash Conditions	5-80
5.4.3 Conformance to Proposed FMVSS 301.	5-83
6. RECOMMENDED DESIGN MODIFICATIONS	6-1
6.1 GENERAL DESIGN CRITERIA	6-1
6.2 FUEL SYSTEMS.	6-3
6.2.1 Fuel Tanks	6-3
6.2.2 Fillers.	6-5
6.2.3 Fuel and Vapor Line Outlets.	6-6
6.2.4 Fuel and Vapor Lines	6-6
6.2.5 Fuel Pumps	6-7
6.2.6 Liquid Fuel Expansion Provisions	6-7
6.2.7 Liquid-Vapor Separators.	6-7
6.2.8 Vapor Storage Containers	6-8
6.2.9 Pressure-Vacuum Relief Provisions.	6-8
6.2.10 Carburetors.	6-8
6.3 ELECTRICAL SYSTEMS.	6-9
6.3.1 Location	6-9
6.3.2 Shielding.	6-10
6.3.3 Inerting	6-10
6.4 EXHAUST SYSTEMS	6-11
7. RECOMMENDED SAFETY PERFORMANCE REQUIREMENTS.	7-1
7.1 GENERAL	7-1
7.2 RECOMMENDED PERFORMANCE REQUIREMENTS.	7-1
7.2.1 Application.	7-1
7.2.2 Definitions.	7-1
7.2.3 Requirements	7-2
7.2.4 Conditions	7-3

TABLE OF CONTENTS (CONTD)

	<u>Page</u>
7.3 BASIS FOR RECOMMENDED PERFORMANCE CRITERIA.	7-3
7.3.1 Test Vehicle	7-4
7.3.2 Vehicle Test Weight.	7-4
7.3.3 Types of Tests	7-4
7.3.4 Types of Barriers.	7-5
7.3.5 Impact Test Speeds	7-7
7.3.6 Roll-Over Tests.	7-11
7.3.7 Fuel Spillage Limit.	7-11
8. RECOMMENDATIONS FOR FURTHER INVESTIGATION.	8-1
9. REFERENCES	9-1
APPENDIXES	
A EVAPORATIVE EMISSION CONTROL SYSTEM EVALUATION SHEET - NON-CRASHED VEHICLE	A-1
B EVAPORATIVE EMISSION CONTROL SYSTEM EVALUATION SHEET - CRASHED VEHICLE.	B-1
C EXTREME TEMPERATURE TESTS	C-1
D PITCH TESTS	D-1
E ROLL-OVER TESTS	E-1
F COMPONENT AND SUBSYSTEM TESTS	F-1
G REAR-END BARRIER TESTS.	G-1

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
4-1	1970 Ford Sedan Evaporative Control System	4-2
4-2	1970 Ford Galaxie Liquid-Vapor Separator.	4-3
4-3	1970 Ford Three-Way Control Valve.	4-4
4-4	1970 Ford Galaxie Canister	4-5
4-5	Cross Section of Ford Carbon Canister.	4-5
4-6	Ford Canister Purge Line to Air Cleaner (1970 Galaxie)	4-6
4-7	1970 Mustang Evaporative Control System.	4-7
4-8	1970 Maverick Evaporative Control System	4-7
4-9	1970 Maverick Vent Connector Assembly.	4-8
4-10	1970 Maverick Liquid-Vapor Separator	4-8
4-11	1971 Ford Liquid-Vapor Separator	4-9
4-12	1971 Mustang Evaporative Control System.	4-10
4-13	1971 Ranchero Evaporative Control System	4-11
4-14	1971 Pinto Evaporative Control System.	4-11
4-15	1971 Pinto Air Cleaner Purge Inlet (with purge hose removed) Showing Flow-Limiting Plug.	4-13
4-16	1970 Ford F-100 Pickup Truck Evaporative Control System	4-13
4-17	1970 Ford F-100 Fuel Tank and Filler	4-14
4-18	1970 Ford F-100 Fuel Tank and Vapor Vent Lines.	4-15
4-19	1971 Ford F-100 Pickup Truck Evaporative Control System	4-16
4-20	1970 Chevrolet Evaporative Control System.	4-16

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
4-21	1970 Chevrolet Evaporative Control System Fuel Tank.	4-17
4-22	1970 Chevrolet Liquid-Vapor Separator Installation	4-18
4-23	1970 Chevrolet Liquid-Vapor Separator.	4-19
4-24	Chevrolet Carbon Canister for Variable Purge System	4-20
4-25	Chevrolet Vapor Hose Routing for Staged Purge System	4-21
4-26	Chevrolet Staged Purge System.	4-21
4-27	1970 Oldsmobile Evaporative Control System . . .	4-22
4-28	1970 Pontiac Evaporative Control System.	4-23
4-29	Pontiac Canister and Valve Assembly.	4-24
4-30	1970 Chevrolet Station Wagon Fuel Tank and Vapor Vent Line.	4-25
4-31	1971 Chevrolet Liquid-Vapor Separator.	4-26
4-32	1971 Chevrolet Liquid-Vapor Separator Installation	4-27
4-33	1971 Chevrolet Vapor Lines From Fuel Tank to Liquid-Vapor Separator.	4-27
4-34	1971 Oldsmobile Evaporative Control System (Delta 88 and Ninety-Eight)	4-28
4-35	1971 Vega Evaporative Control System	4-29
4-36	Vega Evaporative Control System Canister and Hoses.	4-30
4-37	1971 Chevrolet One-Half-Ton Pickup Truck Evaporative Control System	4-31
4-38	1971 Chevrolet Pickup Truck Evaporative Control System Canister and Hoses.	4-32
4-39	1970 Chrysler Evaporative Control System	4-33

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
4-40	1970 Dodge Evaporative Control System.	4-35
4-41	Chrysler Evaporative Control Hose Routing in Engine Compartment.	4-35
4-42	1971 Satellite Fuel Tank and Liquid-Vapor Separator Assembly	4-36
4-43	1971 Cricket Evaporative Control System.	4-37
4-44	1971 Dodge Colt Evaporative Control System	4-38
4-45	1970 American Motors Evaporative Control System (Rebel and Ambassador).	4-40
4-46	American Motors Single Vent Evaporative Control System	4-41
4-47	1971 American Motors Evaporative Control System Canister and Hoses.	4-42
4-48	1970 Volkswagen Sedan Evaporative Control System	4-43
4-49	Carbon Canister in 1970 VW Microbus.	4-44
4-50	1971 VW Super Beetle Fuel Tank	4-45
4-51	1970 Toyota Corolla Evaporative Control System	4-46
4-52	1970 Toyota Corolla Fuel, Expansion, and Vapor Storage Tanks.	4-47
4-53	1970 Toyota Corolla Fuel Tank and Fuel Pump	4-48
4-54	1970 Toyota Crown Evaporative Control System	4-49
5-1	Extended Filler Neck Fill Limiter.	5-2
5-2	Typical Freundlich Adsorption Isotherm	5-5
5-3	Filler Cap Installation in 1971 VW Super Beetle	5-11

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
5-4	Burned Vapor Hose in 1971 AMC Hornet	5-13
5-5	Vapor Hose in Engine Compartment of 1970 Ford Mustang	5-14
5-6	1970 Carburetor Containing Force Fit Plug.	5-16
5-7	Chafing of Vapor Hoses in 1970 Pontiac Catalina	5-16
5-8	Engine Compartment Vapor Hose Routing in 1970 Pontiac Catalina.	5-17
5-9	Vapor Line in 1971 Chevrolet Impala.	5-18
5-10	Metal Coil Protection on 1971 Vega Vapor and Fuel Lines	5-18
5-11	Vapor Purge Line Installation in 1971 Pinto.	5-19
5-12	Vent Connector and Liquid Vapor Separator in 1970 Ford Mustang	5-21
5-13	1971 Dodge Colt Carbon Canister.	5-26
5-14	1971 Volkswagen Squareback After a 30-mph Barrier Impact.	5-28
5-15	Fuel Spray During Sled Test of 1971 Chevelle Fuel System	5-28
5-16	Front Barrier Impacts Permanent Crush Distance Versus Kinetic Energy	5-31
5-17	1970 Toyota Corolla After 30-mph Barrier Test	5-32
5-18	1970 Chevelle Malibu After 30-mph Barrier Test	5-32
5-19	Broken Carburetor Mounting in Barrier- Crashed Toyota Corolla	5-34
5-20	Opel Kadett Fuel Line Following Front Barrier Impact	5-35

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
5-21	1971 Cougar Involved in a Moderate Front End Collision.	5-36
5-22	Engine Compartment Fire Damage in Crashed 1971 Cougar.	5-36
5-23	Battery Damage in Barrier-Tested Ambassador	5-37
5-24	Battery Damage in Barrier-Tested Capri	5-38
5-25	Battery Damage in Barrier-Crashed Pinto.	5-39
5-26	Displaced Battery in Pinto Involved in Minor Front End Collision.	5-40
5-27	Toyota Impact Damage From 30.2-mph Barrier Test	5-43
5-28	Chevelle Impact Damage From 21.8-mph Barrier Test	5-44
5-29	Ambassador Impact Damage From 20.2-mph Barrier Test	5-44
5-30	Pinto Impact Damage From 20.1-mph Barrier Test	5-45
5-31	Dodge Station Wagon Impact Damage From 27.6-mph Barrier Test.	5-45
5-32	Interior Damage in Rear of Dodge Station Wagon.	5-46
5-33	Rear Barrier Impacts Crush Distance Versus Kinetic Energy.	5-47
5-34	Chronology of Crash Events - 1970 Toyota Corolla.	5-49
5-35	Chronology of Crash Events - 1971 Dodge Station Wagon.	5-50
5-36	Chronology of Crash Events - 1970 Chevelle Malibu.	5-51
5-37	Chronology of Crash Events - 1970 AMC Ambassador	5-52

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
5-38	Chronology of Crash Events - 1971 Ford Pinto.	5-53
5-39	Fuel Tank Damage Caused by Rear End Barrier Impacts.	5-54
5-40	Rear End Collision Damage to 1970 Chevelle	5-56
5-41	Filler-Tank Failure in Moderate Rear End Collision.	5-56
5-42	Rear End Collision Damage to 1970 Ford Torino	5-57
5-43	Punctures in Barrier Crashed Pinto Fuel Tank	5-57
5-44	Severe Rear End Collision Damage in 1971 Chevelle Malibu.	5-58
5-45	Fuel Tank Damage Caused by Differential Housing During Severe Rear End Collision.	5-59
5-46	Fuel Tank Puncture Caused by Striking Vehicle During Severe Rear End Collision.	5-59
5-47	Toyota Fuel Tank Following 30-mph Barrier Test	5-60
5-48	Broken Fuel and Vapor Lines in Barrier-Tested Toyota.	5-61
5-49	Fuel Tank in Dodge Station Wagon Following Barrier Test	5-62
5-50	Post-test View of Dodge Station Wagon Filler Cap	5-62
5-51	Fire Damage in 1970 Mustang Involved in Moderate Rear End Collision.	5-64
5-52	Exhaust Pipe Separation in Barrier-Tested Pinto	5-65

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
5-53	Typical Side Impact Damage	5-67
5-54	Typical Station Wagon Fuel Tank Installation	5-67
5-55	Chevrolet Vega Fuel Tank Installation.	5-68
5-56	Fuel Spillage From Chevelle Canister With Vehicle in 45-Degree Nose-Down Position	5-73
5-57	Fuel Spillage From Damaged Vapor Hose in AMC Hornet.	5-75
5-58	Fuel Spillage From Broken Fuel Line in AMC Ambassador	5-76
5-59	Inverted Resting Position of AMC Ambassador	5-76
5-60	Fuel Spillage From Damaged Vapor Hose in AMC Ambassador.	5-78
5-61	Vapor Hose Damage in Ambassador From Rear Barrier Test.	5-78
D-1	Maximum 60-Degree Pitch Attitudes.	D-2
F-1	Drop Tower/Horizontal Sled Facility.	F-3
F-2	Test Setup for Test 1 (Mustang Subsystem).	F-5
F-3	Test Setup for Test 2 (Mustang Subsystem).	F-5
F-4	Test Setup for Test 3 (Chevelle Subsystem)	F-6
F-5	Test Setup for Test 4 (Chevelle Subsystem)	F-6
F-6	Test Setup for Test 5 (Volkswagen Subsystem)	F-7
F-7	Test Setup for Test 6 (Toyota Subsystem)	F-7
F-8	Test Setup for Test 7.	F-8
F-9	Test Setup for Test 8.	F-8

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
F-10	Test Setup for Test 9.	F-9
F-11	Test Setup for Test 10	F-9
F-12	Chevelle Fuel Tank Damage - Rear Impact Sled Test (Test 4)	F-12
F-13	Displaced Volkswagen Fuel Tank - Front Impact Sled Test (Test 5).	F-12
G-1	Full-Scale Crash Test Facility	G-2
G-2	Pre- and Post-test Views of Toyota Corolla.	G-5
G-3	Pre- and Post-test Views of Dodge Station Wagon.	G-7
G-4	Acceleration-Time Histories, Occupant Compartment - Dodge Station Wagon.	G-8
G-5	Acceleration-Time Histories, Engine - Dodge Station Wagon.	G-9
G-6	Acceleration-Time Histories, Frame - Dodge Station Wagon.	G-10
G-7	Acceleration-Time Histories, Fuel Tank Area - Dodge Station Wagon	G-11
G-8	Force-Time Histories, Barrier Load Cells - Dodge Station Wagon.	G-12
G-9	Longitudinal Acceleration-Time Histories and Velocity Changes - Dodge Station Wagon.	G-13
G-10	Longitudinal Acceleration-Time Histories and Velocity Changes - Dodge Station Wagon.	G-14
G-11	Force-Time Histories and Impulses, Barrier Load Cells - Dodge Station Wagon.	G-15
G-12	Pre- and Post-test Views of Chevelle Malibu	G-17

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
G-13	Acceleration-Time History, Occupant Compartment - Chevelle	G-18
G-14	Acceleration-Time History, Engine - Chevelle	G-19
G-15	Acceleration-Time Histories, Frame - Chevelle	G-20
G-16	Acceleration-Time Histories, Fuel Tank Area - Chevelle.	G-21
G-17	Force-Time Histories, Barrier Load Cells - Chevelle	G-22
G-18	Longitudinal Acceleration-Time Histories and Velocity Changes - Chevelle.	G-23
G-19	Longitudinal Acceleration-Time Histories and Velocity Changes - Chevelle.	G-24
G-20	Force-Time Histories and Impulses, Barrier Load Cells - Chevelle.	G-25
G-21	Force-Time Histories and Impulses, Barrier Load Cells - Chevelle.	G-26
G-22	Pre- and Post-test Views of AMC Ambassador	G-28
G-23	Acceleration-Time Histories, Occupant Compartment - AMC Ambassador	G-29
G-24	Acceleration-Time Histories, Engine - AMC Ambassador	G-30
G-25	Acceleration-Time Histories, Frame - AMC Ambassador	G-31
G-26	Acceleration-Time Histories, Fuel Tank Area - AMC Ambassador.	G-32
G-27	Force-Time Histories, Barrier Load Cells - AMC Ambassador	G-33
G-28	Longitudinal Acceleration-Time Histories and Velocity Changes - AMC Ambassador.	G-34

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
G-29	Force-Time Histories and Impulses, Barrier Load Cells - AMC Ambassador.	G-35
G-30	Pre- and Post-test Views of Ford Pinto	G-37
G-31	Acceleration-Time Histories, Occupant Compartment - Ford Pinto	G-39
G-32	Acceleration-Time Histories, Engine - Ford Pinto	G-40
G-33	Acceleration-Time Histories, Frame - Ford Pinto	G-41
G-34	Acceleration-Time Histories, Fuel Tank Area - Ford Pinto.	G-42
G-35	Force-Time Histories, Barrier Load Cells - Ford Pinto	G-43
G-36	Longitudinal Acceleration-Time Histories and Velocity Changes - Ford Pinto.	G-44
G-37	Force-Time Histories and Impulses, Barrier Load Cells - Ford Pinto.	G-45

LIST OF TABLES

<u>Table</u>		<u>Page</u>
2-I	Frequency of Motor Vehicle Fire Accidents.	2-1
2-II	Fire Accidents by Accident Type.	2-2
2-III	Frequency Versus Severity of Accidents	2-3
2-IV	Fire Damage Versus Fire Accident Severity.	2-3
2-V	Frequency and Severity of Fire Accidents by Impact Type	2-4
2-VI	Fuel System Leakage by Impact Area	2-5
2-VII	Impact Area Contribution to Leakage for Various Fuel Tank-Filler Configurations.	2-5
3-I	New Vehicles Analyzed.	3-2
3-II	Crashed Vehicles Analyzed.	3-4
5-I	Front Barrier Impacts - Test Data.	5-30
5-II	Rear Barrier Impacts - Basic Test Data	5-43
5-III	Peak Accelerations - Rear Impact Barrier Tests.	5-48
5-IV	Fuel Tank Crushing Sustained During Rear Barrier Tests	5-55
5-V	Filler Cap Pressure Relief Valve Spillage During Roll-Over and Pitch Tests	5-71
5-VI	Crush Distance Per Kinetic Energy Increment - Front and Rear Barrier Impacts.	5-81
7-I	Moving-Barrier Velocities Equivalent to Fixed-Barrier Velocities	7-8
C-I	Extreme Temperature Test Data.	C-3
F-I	Component and Subsystem Test Matrix.	F-4
F-II	Component and Subsystem Acceleration- Time Test Data	F-11

LIST OF TABLES (CONTD)

<u>Table</u>		<u>Page</u>
G-I	Accelerometer Locations.	G-2
G-II	Vehicle Weights and Impact Velocities.	G-3
G-III	Permanent Crush Distances of Ford Pinto.	G-38
G-IV	Total Velocity Change During Rear Impact Barrier Tests.	G-46
G-V	Barrier Impulse During Rear Impact Barrier Tests.	G-47

1. INTRODUCTION

This report culminates a 17-month program structured to identify potential fire hazards in automotive fuel systems. Primary emphasis was placed on investigating evaporative emission control systems required by Federal regulations on all 1971 automobiles and by California state regulations on 1970 automobiles for sale in California. Electrical and exhaust systems were investigated in conjunction with the fuel systems since they may inadvertently provide ignition sources in the event of fuel leakage.

This program was conducted for the National Highway Traffic Safety Administration under Contract FH-11-7579, entitled "Electrical, Fuel, and Exhaust System Integrity". An important objective of this study was to generate an information base from which NHTSA could develop motor vehicle safety standards intended to protect motor vehicle occupants from fire hazards associated with the failure of the fuel, electrical, and exhaust systems in crash and/or roll-over accidents by preventing fuel spillage or suppressing ignition of spilled fuel.

An important factor prompting the initiation of the study was the incorporation of fuel evaporative emission control systems on many vehicles in 1970 and 1971. These systems significantly increased the complexity of the fuel systems and could possibly lead to unique fuel spillage patterns during either operational or crash conditions, and thus create an increased fire hazard. Accordingly, this study included those vehicles in the Gross Vehicle Weight (GVW) class of 6,000 pounds or less (passenger cars, trucks, buses, and multi-purpose vehicles) that were equipped with fuel evaporative emission control systems and had a sales record of at least 500 units per model year.

Although the percentage of accidents resulting in post-crash fires is less than 0.5 percent, the large number of accidents occurring every year results in a significant number of accidents involving post-crash fires. In addition, the catastrophic nature of a fire accident results in a disproportionately higher number of injuries and deaths. In recognition of this fact, the Federal Highway Administration issued Federal Motor Vehicle Safety Standard 301,* effective January 1, 1968, imposing limits on fuel spillage in a front-end collision test. More recently, in a continuing effort to reduce the deaths and injuries resulting from motor vehicle post-crash fires, the National Highway Traffic Safety Administration has proposed modifications to the present 301 standard which not only reduce the amount of allowable fuel spillage but require that compliance with the leakage specification also be demonstrated in a rear-end

*FMVSS 301, "Fuel Tanks, Fuel Tank Filler Pipes, and Fuel Tank Connections - Passenger Cars".

impact and subsequent roll-over test. This program conducted by Dynamic Science for NHTSA provides analytical and experimental documentation for fuel system performance in both operational and crash environments.

An integrated approach combining vehicle analysis and vehicle testing was used to determine the fire hazards of the electrical, fuel, and exhaust systems. Major effort was concentrated on the fuel and evaporative emission control systems, with the electrical and exhaust systems being analyzed only as potential ignition sources for spilled fuel. Brief descriptions of the tasks involved in this effort follow:

1. New Vehicle Analyses: Twenty-seven 1970 and 1971 vehicles were analyzed to identify design and performance elements of the fuel system/components that, on interaction with the electrical and exhaust systems/components, could contribute to motor vehicle fuel fire under both operating and crash conditions.
2. Crashed Vehicle Analyses: Thirty-five crashed vehicles were analyzed to determine the crash effects on the fuel, electrical, and exhaust systems and on the relations between these systems. These vehicles included 12 subjected to front-end barrier tests under other contracts, 5 subjected to rear-end barrier tests under this program, and 4 involved in actual post-crash fire accidents. The remaining 14 had been involved in actual non-fire accidents.
3. Extreme Temperature Tests: Five vehicles were tested to identify any conditions of the fuel system, including the evaporative emission control system, which would constitute a safety hazard when the vehicles are subjected to high environmental temperatures.
4. Attitude Tests: Attitude tests involving vehicle pitch (5 vehicles) and roll-over (5 vehicles) were conducted to assess the possibility of spillage from the fuel system when the vehicle comes to rest in an extreme front-up or front-down attitude following an accident or when the vehicle is involved in a roll-over accident.
5. Component Tests: Ten dynamic tests (9 sled runs and 1 drop test) were conducted to assess the integrity of automotive fuel evaporative emission control subsystems, components, and their attachments when subjected to typical automobile crash decelerations.
6. Rear-End Barrier Crashes: Five vehicles were tested to assess the integrity of the automotive fuel and fuel evaporative emission control systems when subjected to rear-end impacts.

The report has been organized to assist the nontechnical reader in assimilating the overall context and results of the studies, as well as to furnish details which might be of interest to other researchers. Brief discussions of the analyses and testing conducted during the program are presented in Section 3.0 (Approach), while detailed test conditions and test results are presented in the Appendices.

Detailed descriptions of the fuel and evaporative emission control systems for all of the new vehicles which were analyzed are presented in Section 4.0 (Fuel System Designs). The results of the new and crashed vehicle analyses and the testing program have been integrated to provide the comprehensive and detailed analyses of the fuel system fire hazards presented in Section 5.0 (Fuel System Fire Hazards). Appropriate references to specific system design details described in Section 4.0 have been provided in Section 5.0 to assist the reader in understanding the analyses. A brief summary of the analyses is presented at the end of Section 5.0.

The results of the vehicle analyses and testing program were used as a basis for recommending modifications to the present systems to improve their safety performance relative to their integrity. These recommendations, presented in Section 6.0 (Recommended Design Modifications) are primarily techniques to prevent fuel or fuel vapor from impinging into/on the occupant compartment, or to prevent spillage which might be ignited during crash impact. Recommendations or modifications for the electrical and exhaust systems were also made where obvious fire hazards existed. In addition, the recommendations are priority oriented based on the seriousness of the threat which they are designed to eliminate.

Improved safety performance requirements based on the results of this study have been recommended in Section 7.0 (Recommended Safety Performance Requirements). The basis for these improved performance requirements are set forth in detail and any problems which might arise in meeting them are discussed.

2. BACKGROUND

Although the rapidly increasing number of injuries and fatalities resulting from motor vehicle accidents has prompted a large number of studies in vehicle crashworthiness and occupant protection, relatively few studies have been concentrated in the area of post-crash fire prevention. Moreover, most of the work done in this area has been fairly recent. Therefore, a brief description of prior work done in relation to motor vehicle crash fires is presented below.

2.1 ACCIDENT STATISTICS

2.1.1 Fire Accidents. Accident statistics on motor vehicle fires are quite limited as most reporting agencies do not include a separate category for fire accidents in their reporting media. There have been three statistical studies conducted, however, which, although based on limited data, do give some insight into the fire problem. Two of the studies were conducted in 1963 and 1964, while the most recent (in New York State) was conducted in 1969.

All of these studies found that the frequency of fires occurring in motor vehicle accidents was quite low, as may be seen in Table 2-I. The California (Ref 1) and Cornell Automotive Crash Injury Research Division (ACIR) (Ref 2) studies were conducted on fatal and injury-producing accidents only, while the New York study (Ref 3) was based on all accidents during the reported periods of March and September, 1968. The low frequency of fire accidents is somewhat misleading, however, as, based on the 15-1/2 million motor vehicle accidents reported for 1969 by the National Safety Council, even the lowest percentage (.04) indicates over 6,000 fire accidents in this country during 1969.

TABLE 2-I. FREQUENCY OF MOTOR VEHICLE FIRE ACCIDENTS					
Source	Fatal Accidents (%)	Combined Fatal and Injury- Producing Accidents (%)	Personal Injury Accidents (%)	Property Damage Accidents (%)	Total (%)
California (Ref 1)	1.47	0.26	.04	-	-
ACIR (Ref 2)	-	0.45 ⁽¹⁾	-	-	-
New York State (Ref 3)	2.38	-	.06	.04	.07
(1) Percent of passenger cars involved in fatal and injury-producing accidents.					

Forty-nine percent of the fire accidents in the New York survey resulted from a collision with another motor vehicle or a fixed object (Table 2-II). Twenty-two percent of the fire accidents occurred during single vehicle off-road or overturning accidents. Twenty-nine percent of the fire accidents consisted of vehicles being driven under normal conditions and catching fire without impact. All of these special non-collision fire accidents occurred in the month of September with none in the month of March. It was the opinion of the investigators that the increase was most likely due to higher ambient road temperatures in September.

TABLE 2-II. FIRE ACCIDENTS BY ACCIDENT TYPE	
Accident Type	Percentage of Total Fire Accidents
Collision With Other Motor Vehicle	33
Collision With Fixed Object	16
Single Vehicle; Ran Off Road or Overturned On Road	22
Special Non-Collision; Vehicle Caught Fire While In Motion	29

The frequency of fire in motor vehicle accidents increases with the severity of the accident. This is evident not only from Table 2-I, which shows a much higher percentage of fires associated with fatal accidents than with injury or property damage accidents, but also in Tables 2-III and 2-IV. Table 2-III, based on the New York study, shows that, although fatal accidents occurred in only 1 percent of all the accidents investigated, fatal accidents were present in 24 percent of the fire accidents which occurred. Table 2-IV, taken from the ACIR study, compares the extent of fire damage with the accident severity based on the degree of vehicle structural damage. Table 2-IV not only shows that fires are more likely to occur during more severe accidents, but also that the fire damage increases as the severity of the accident increases.

Additional support for the statement that fire accidents are more likely to occur during severe and, therefore, higher speed accidents, is found in the New York State survey which disclosed that 42 percent of the fire accidents occurred on the thruway, interstate, or expressway road systems, although fewer than 5 percent of the total accidents occurred on these roads. This

based on N.Y. Study

TABLE 2-III. FREQUENCY VERSUS SEVERITY OF ACCIDENTS		
Accident Severity	Percentage in All Accidents	Percentage in Fire Accidents
Fatality	1	24
Personal Injury	55	49
Property Damage	44	27

based on ACIR Study

TABLE 2-IV. FIRE DAMAGE VERSUS FIRE ACCIDENT SEVERITY				
Accident Severity*	Percent of Fire Accidents	Extent of Fire Damage		
		Minor (%)	Major (%)	Extreme (%)
Minor-Moderate	18	17	54	29
Moderately Severe	41	5	59	36
Severe-Extreme	41	4	36	60
*Based on structural damage.				

fact, coupled with the fact that the non-collision fires were present only during the hotter month, led the New York State researchers to recognize that the fire problem could be far greater in other geographical areas with warmer temperatures and where a major portion of travel is on high-speed expressways.

The ACIR study also analyzed the fire accidents by impact type; these data are summarized in Table (2-V). An examination of these data leads to the conclusion that the roll-over accident is the most serious from a fire threat. Roll-over accidents accounted for as many fire accidents as did front impacts, although roll-overs occurred with only one-third the frequency. Eighty percent of the roll-over fire accidents resulted in extreme fire damage to the vehicle and accounted for almost 80 percent of all the burn fatalities.

The rear impact accident must be rated as the second highest fire threat to a vehicle occupant. Although rear end impacts were involved in only 5 percent of all the accidents studied, they contributed 17 percent of the fire accidents and resulted in more burn injuries than did the front impact accidents. Front impact fire accidents cannot be ignored, however, because front impacts occur in almost 70 percent of all accidents. Thus,

based on ACIR data

TABLE 2-V. FREQUENCY AND SEVERITY OF FIRE ACCIDENTS BY IMPACT TYPE							
Impact Type	Percentage of All Accidents	Percentage of Total Fire Accidents	Extent of Fire Damage			Fire Accident Occupants Suffering Non-Fatal Burns (%)	Fire Accident Occupants Suffering Fatal Burns (%)
			Minor (%)	Major (%)	Extreme (%)		
Front	69	42	6	65	29	7	4
Rear	5	17	4	70	26	14	3
Roll-over	23	41	8	12	80	3	23

although the fire hazard to the occupant is not as great during a front collision, the high number of front collision accidents contributes significantly to the total fire problem. It is interesting to note that no difference in the incidence of fire was observed between front-engine and rear-engine passenger cars.

2.1.2 Fuel System Damage. A recent study by the Cornell Aeronautical Laboratory (Ref 4) analyzed vehicle accident data for fuel system damage and leakage. This study was based on data obtained from over 2,000 vehicles involved in injury-producing collisions for the 10-month period between June 1968 and March 1969. Table 2-VI summarizes the data found during collision accidents by impact area (excluding roll-over accidents not involving a collision). These data show that impacts to the rear or the rear quarter panels are much more likely to produce fuel system leakage than are impacts in the front of the vehicle. Rear impacts, although involved in only 10 percent of all the collisions, contributed 36.6 percent of all the fuel system leaks. Front impacts are ranked second in percent contribution to all leaks simply because of the high percentage of all impacts involving front collisions. Rear quarter panel collisions are ranked next in percent contribution to all leaks. It is interesting to note the very slight difference between right and left rear quarter panel impact leaks, since all of the fuel tanks equipped with side fillers had them on the left side.

The CAL study also determined the percentage of leaks by impact area for various fuel tank-filler configurations, as shown in Table 2-VII. This table clearly shows the areas most sensitive to impact for the various configurations. As might be expected, the rear tanks are more sensitive to rear impacts while the front tanks are more sensitive to front impacts. The mid-tank (defined in the study as a tank located just behind the rear axle in the step-up area under the vehicle floor) shows a marked sensitivity to all the impact areas, while the fender tank shows a marked sensitivity to impacts in the left rear quarter panel containing the filler. The absolute percentages, however, should not be construed as completely defining the impact areas which

CAL (Brayman)

TABLE 2-VI. FUEL SYSTEM LEAKAGE BY IMPACT AREA

Automobile Body Impact Area	Percent of Total Impacts	Percent of Impacts Resulting In Leaks	Percent Contribution to All Leaks
Front	66.5	3.5	32.7
Left Side-Front	5.5	6.5	4.9
Right Side-Front	6.6	3.3	3.0
Left Side-Rear	5.9	14.6	11.9
Right Side-Rear	5.5	14.3	10.9
Rear	10.0	26.4	36.6
Percent leaks of all impacts = 7.2.			

CAL (Brayman)

TABLE 2-VII. IMPACT AREA CONTRIBUTION TO LEAKAGE FOR VARIOUS FUEL TANK-FILLER CONFIGURATIONS

Tank-Filler Configuration	Total Number of Vehicles Involved	Percent of Impacts Resulting in Leaks	Percent of Area Impacts Resulting in Leaks					
			Front	Left Side Front	Right Side Front	Left Side Rear	Right Side Rear	Rear
Rear Tank-Rear Filler	831	6.9	3.4	4.3	1.7	14.0	18.2	26.0
Rear Tank-Left Filler	246	7.7	2.0	5.9	0	12.5	7.7	35.3
Fender Tank-Left Filler	60	3.0	0	0	0	40.0	0	0
Mid-Tank, Left Filler	190	10.0	6.6	16.7	11.1	11.1	16.7	29.4
Front Tank-Left, Right, and Top Filler	75	6.7	6.5	16.7	14.3	0	0	0

can result in leakage, especially for the fender tanks and front tanks, which consisted of relatively small sample sizes. One cannot say that the only impact which will result in fender tank leakage is to the left rear quarter panel, or that only front impacts result in leakage from front tank systems. The percentages do, however, offer a fair comparison on the sensitivity of the impact areas in relation to each other.

2.1.3 Summary. It is tempting to draw many correlations from the available statistical data. However, the small sample sizes and the different bases from which the samples were drawn makes most such correlations speculative at best, and much more statistical data is necessary on fire accidents if valid correlations are to be made. There are two inescapable conclusions, however. One is that, even though the incidence of fire accidents is very low, the number of fire accidents is large enough to present a significant hazard because of the large total number of accidents which occur. The data also clearly show that fuel system leakage and fire accidents can, and do, occur in all types of accident situations.

2.2 FUEL SYSTEM STUDIES

Although the number of studies devoted to vehicle fuel system leakage during collisions is extremely limited, these studies have provided insight into several modes of fuel system failures during crashes.

A series of vehicle-to-vehicle rear end collision tests was conducted using standard 1967 Ford sedans with the mid-tank fuel system configuration (Ref 5). Seven of the twelve tests were conducted at 30 mph, one at 10, one at 20, one at 40, and two at 55 mph.

The only test in which fuel spillage did not occur was the one conducted at 10 mph. The 20-mph test resulted in extensive fuel spraying because the filler pipe pulled free from the fuel tank connection. Four of the 30-mph tests resulted in either the filler pipe being pulled from the tank or in rupturing of the fuel tank. Although the ruptures were not described in detail, one test at 30 mph resulted in the fuel tank being punctured by the lower transverse stabilizer attachment bolt.

The 30-mph tests conducted later in the program showed a significant reduction of fuel leakage because of an improvement made by the manufacturer in the filler spout. The lengthening of the spout portion protruding into the fuel tank eliminated the problem of the filler pipe being pulled free during the collision. The 40-mph test punctured the fuel tank in the front center, but the filler spout did remain attached.

In both 55-mph tests massive spillage occurred from the fuel tank, either by the tank splitting at the seams or by being punctured. In one of the tests the production tank was modified by adding a rubber-like inner bladder and filling the entire tank space with an open-cell, low-density foam material to reduce the rate of fuel drainage from a ruptured tank. However, the tank and bladder were punctured sufficiently to allow most of the fuel to drain rapidly from the tank, showing that this arrangement did not provide the desired protection, at least during a high-speed

rear end collision. In this same test a second fuel tank was installed in the trunk (on the floor pan axle step over the rear axle) for the purpose of evaluating the practicality of this position for fuel tanks. The only damage to this tank consisted of it being collapsed inward approximately 2 inches, which displaced enough fluid to force the filler cap from the filler spout. There was no other leakage from the tank.

A later test conducted in this series involved the intentional ignition of a post-crash fire to study the hazards to the passengers (Ref 6). By the time the rear-ended car, which was struck at 55 mph, had advanced 2 feet, gasoline could be seen spurting from the rear wheel area. By the time the rear-ended car had traveled approximately 8 feet, the gasoline had erupted forward to the front wheel area and had spread out several feet on each side of the car. During this test, an igniter had been provided 40 feet ahead and 8 feet to the side of the initial impact point. The gasoline cloud reached the igniter within 0.6 second after impact, resulting in a catastrophic fire which enveloped both cars. High-speed cameras mounted on the struck car showed that the fire burned violently outside of the rear portion of the passenger compartment for 7 seconds, without any flames showing inside even though the rear window had been broken out. After 7 seconds had passed, a small flame appeared at the right of the right rear passenger and 2 seconds later the flame appeared on the other side of the passenger. It appeared to have burned from the open trunk area through the base of the rear seat. Thermocouples within the vehicle showed that the potential escape time from this vehicle was only 60 seconds. Escape from the striking car was highly improbable, as the striking car rolled squarely onto the flaming fuel from the burst tank and was completely engulfed in flames within 2 seconds after impact.

Fuel system damage was also monitored on 11 crash tests conducted at Cornell (Ref 4). Although the primary purpose of these tests was not the investigation of the fuel systems, the tests were useful in pinpointing some types of fuel system failures. All of the tests were barrier-type tests which included front and side pole impacts, vehicle underride impacts, and compliance test front barrier impacts. A variety of vehicles was also tested, ranging from a 1961 Volkswagen to a 1969 Buick Special.

Leakage resulted in various systems due to filler cap dislocations, surge seepage around the filler neck O-ring seal, fuel line disconnection, and the puncturing of a 1966 Ford sedan fuel tank by the lower transverse stabilizer attachment bolt, as was also found in the tests conducted by Severy, et al. It should be pointed out that Ford modified the sedans in 1967 by installing a rubber cap over the stabilizer bar bolt to reduce the incidence of fuel tank puncture caused by the bolt.

The above fuel system tests show that fuel leakage can occur from the fuel tank and fuel system even at low impact speeds from a variety of causes, each dependent upon the particular system involved. High impact speed can cause rupturing of the fuel tank during impact. However, this type of failure is seen only in severe impacts and fuel system leakage could be considerably reduced during lower speed collisions by simple modifications to the rest of the fuel system.

Two analytical studies of motor vehicle fuel systems have also been conducted. These studies examined vehicle fuel systems for potential crash fire hazards and recommended improved design and test standards for vehicle fuel system protection (Refs 1 and 7). Many of the recommendations for improved fuel systems are based on extensive aircraft studies which were conducted to determine fuel system failure modes during crashes and to develop crashworthy aircraft fuel systems. The data generated in these programs are, in general, directly applicable to ground vehicles, and the same basic principles of maintaining fuel system integrity apply to both (Ref 8). It should also be pointed out that a large part of the automotive fuel system safety work is based on these analytical studies and on aircraft practices and recommendations.

2.3 IGNITION SOURCE STUDIES

Aircraft studies have shown that spilled fuel may be ignited by damaged electrical systems, hot engine and exhaust parts, exposed landing light filaments, and friction sparks generated by the scraping of metal against paved surfaces or other hard objects. Studies of automotive ignition sources indicate that the same factors, with the possible exception of light filaments, are involved in ignition of automotive fires.

The vehicle electrical system can and does function as an ignition source for spilled fuel. Laboratory studies by the FIAT Auto-Avio Research Laboratory (Ref 9) showed that the open circuiting of a wire followed by an extra current spark, such as might happen when wires are severed or when severed wires contact grounded structure, produced ignition of gasoline-air mixtures in a high percentage of cases. Attempts by these researchers to ignite flammable gasoline-air vapors with overheated wires was unsuccessful even when the wire was red hot. However, when the heated wire finally melted and broke, with consequent sparking, ignition did take place.

The battery is a particularly hazardous component from a fire ignition standpoint for two reasons. First, the battery is capable of producing a spark even when disconnected from the electrical system, and, second, the FIAT researchers found that even when the battery was practically destroyed, with a loss of electrolyte, the voltage and output capacity was still available.

Analytical studies of numerous vehicle electrical installations (Refs 7 and 10) found that the most hazardous components in the automotive electrical system are the high capacity components such as the battery, voltage regulator, alternator/generator, starter solenoid, and the wiring associated with these components. These components and their wiring are often located near the exterior of the vehicle where they are vulnerable to crash damage and could easily function as electrical spark ignition sources.

The FIAT researchers also demonstrated that friction sparks resulting from dragging the body of a heavily damaged car over several types of pavement could ignite gasoline spilled in the same area. It was observed that, up to a speed of 20 kilometers per hour (12.5 mph), no sparking occurred. However, at higher speeds ignition took place in 10 percent of the tests.

Fairchild Hiller (Ref 7) conducted an extensive investigation of vehicle exhaust systems as they might relate to post-crash fire safety. They found that the temperature of all of the exhaust system components except the front pipe are well below the autogenous ignition temperature of gasoline, which ranges from 550 to 850°F depending on the octane rating. Some doubt exists as to whether even the front pipe temperature is sufficient to cause fuel ignition. The real danger of the exhaust system lies in the fact that the high temperatures of these components will readily vaporize any liquid gasoline spilled on them. This vaporized fuel may then mix with air to form flammable fuel-air ratios which can be ignited by either electrical or friction sparks.

2.4 LIMITATIONS OF PREVIOUS STUDIES

Many of the limitations of the previous studies have been alluded to above. These include the limited number of tests which have been conducted and the limited number of fuel system configurations which have been tested. In addition, little quantitative data on the fuel systems were gathered during the tests because the tests were designed mainly to investigate other problems and not specifically the integrity of the fuel system.

The biggest limitation of the previous studies, however, is that they were all conducted on pre-1970 vehicles, while the fuel systems of many 1970 and all 1971 and subsequent model year cars have been modified extensively to meet new fuel evaporative emission regulations.

The State of California established regulations limiting fuel evaporative losses from fuel systems in 1970 and later model gasoline-powered motor vehicles under 6,000 pounds GVW. The Department of Health, Education, and Welfare required the same limitations on the same class of vehicles beginning with the 1971 model year. In order to meet these emission requirements, the

automobile manufacturers added fuel evaporative emission control systems to the regular fuel systems.

The evaporative emission control systems prevent vapor from being vented into the atmosphere directly from the fuel tank by trapping the vapor and storing it until it can be routed into the engine and burned during engine operation. The complexity of the systems pose some unique possibilities for fuel spillage during crash impact which did not exist in earlier fuel systems. Thus, although the previous studies are still applicable to those parts of the fuel systems which have remained essentially unchanged, the evaluation of the fire hazard inherent in the new vehicles on the road today could not be assessed without detailed study of the new fuel systems in these vehicles. Thus, one of the primary purposes of this program was to identify the potential fire hazards of the various designs of fuel evaporative emission control devices as they may contribute to fuel spillage and fuel vapor loss under normal and crash conditions.

3. APPROACH

3.1 GENERAL

An integrated approach of vehicle analysis and testing was used to assess the fire hazards of the electrical, fuel, and exhaust systems during operational and crash conditions. The major effort was concentrated on the fuel and evaporative emission control systems, with the electrical and exhaust systems being analyzed only as potential ignition sources for spilled fuel.

The program consisted of a detailed analysis of the vehicle structure and fuel, electrical, and exhaust systems, and their interaction during crash conditions. Readily apparent operating hazards were also noted. A comprehensive plan of component, system and subsystem testing as well as full-scale vehicle crash testing was utilized to provide a definitive base for the assessment of the actual fire hazard. Based on the results of the vehicle analyses and the testing program, modifications were proposed to the present systems to obtain improved safety performance and a decrease in their fire hazard potential.

3.2 NEW VEHICLE ANALYSES

The primary purpose of the analyses was to identify the potential fire hazard of the various fuel evaporative emission control devices as they could contribute to fuel spillage and/or fuel vapor loss under normal and crash conditions. Thus, this effort included only those vehicles in the GVW class of 6,000 pounds or less that were equipped with fuel evaporative emission control devices. These devices were first required on 1970 model vehicles for sale in California and subsequently on all 1971 model vehicles under 6,000 pounds GVW. The vehicles analyzed were examined in dealer showrooms or were obtained from rental agencies and, in some cases, from private individuals.

Since an exhaustive study of all makes and models of vehicles equipped with these devices was outside the scope of this program, a representative sample of these vehicles was carefully selected for analysis. The selection included a representative number of vehicles in the different categories of front engine passenger cars, rear engine passengers cars, light trucks, and station wagons, as these are the most common types of vehicles in this weight class. In addition, the vehicles selected represented the basic types of fuel evaporative emission control systems and the major manufacturers. Both 1970 and 1971 models were analyzed to reveal any changes between the two model years. The vehicles chosen for analysis are shown in Table 3-I.

TABLE 3-I. NEW VEHICLES ANALYZED	
1970 (13 Vehicles)	1971 (14 Vehicles)
American Motors Rebel	American Motors Gremlin
Chevrolets:	Chevrolets:
Caprice	Impala
Station Wagon	1/2-Ton Pickup
Dodge Polara	Vega
Fords:	Dodge Colt
Galaxie	Fords:
Maverick	Mustang
Mustang	Pinto
1/2-Ton Pickup	Ranchero
Oldsmobile Cutlass	Oldsmobile Cutlass
Pontiac Catalina	Plymouths:
Toyota Corolla	Cricket
Volkswagens:	Satellite
Microbus	Toyotas:
Sedan ("Beetle")	Corolla
	Corona
	Volkswagen Sedan ("Super Beetle")

The analyses were performed to identify design and performance elements of the fuel system/components that, on interaction with the electrical and exhaust system/components, could contribute to motor vehicle fuel fire. Although primary emphasis was placed on the analyses of the fuel systems, special attention was given to possible interactions of the fuel system with electrical and exhaust system components which could lead to fire ignition. The analyses included the following:

- Areas susceptible to loss of integrity by crash or normal deterioration.
- Effects of extreme environmental or operational temperatures, mechanical vibration, and normal acceleration loads.

- Effects of vehicle attitude or other vehicle use circumstances on the system as a whole.
- Component design, including structural strength.
- Effect on the system of a component malfunction.
- Effect of maintenance errors or omissions on the components and system.

The evaluation form used for the new vehicle analyses is shown in Appendix A.

3.3 CRASHED VEHICLE ANALYSES

The primary source of crashed vehicles were those vehicles involved in actual accidents which were located in automobile salvage yards. In so far as was possible, a representative sample of various vehicle models, manufacturers, and accident modes were examined. An additional source of crashed vehicles were those subjected to front end barrier impacts at the Dynamic Science facility under other NHTSA programs and 5 vehicles subjected to rear end barrier impacts during this program. A total of 35 crashed vehicles were analyzed, including 4 vehicles involved in post-crash fires. These vehicles are listed in Table 3-II.

These vehicles were analyzed to determine the crash effects on the fuel, electrical, and exhaust systems and on the relations between these systems. By assessing the crash damage of the three systems, together with the vehicle structural damage and the type of crash impact, potential fire hazards related to impact types could be established. This analysis also helped to determine probable failure modes of the three systems and especially hazardous locations of the system components. The evaluation form used for the crashed vehicle analyses is shown in Appendix B.

3.4 TESTING

The testing program was designed to supplement and more accurately define the hazards determined during the vehicle analyses. The program consisted of non-crash studies of the effects of vehicle attitude and temperature, component and subsystem simulated crash tests, and full-scale vehicle crash tests. A brief description of these tests follows. Detailed descriptions and test results are presented in Appendixes C through G.

3.4.1 Extreme Temperature Tests. The objective of these tests was to identify any condition of the fuel system, including the evaporative emission control system, which could constitute a safety hazard when the automobile is in use in

TABLE 3-II. CRASHED VEHICLES ANALYZED	
Vehicles Involved in Automobile Accidents	
1970	1971
American Motors Hornet Buick Special Chevrolet Chevelle Malibu Fords: Mustang Mach I Torino Mercury Brougham Plymouth Valiant Pontiac Catalina (2) Toyotas: Corolla Corona Mark II Triumph Spitfire Volkswagen Sedan ("Beetle")	Chevrolet Chevelle Malibu Ford Pinto (2) Mercury Cougar Toyota Corolla
Vehicles Subjected to Front Impact Barrier Crashes	
1970	1971
American Motors Ambassador Austin American Sedan Chevelle Malibu Fiat 124 Sedan (2) Toyota Corolla	Capri Sport Coupe Dodge Station Wagon Fiat 124 Coupe Ford Pinto Opel Kadett Station Wagon Volkswagen Squareback
Vehicles Subjected to Rear Impact Barrier Crashes	
1970	1971
American Motors Ambassador Chevelle Malibu Toyota Corolla	Dodge Station Wagon Ford Pinto

geographical locations having high daytime temperatures. The tests were conducted on four automobiles representing various evaporative emission control systems.

The vehicle fuel tank was filled to its spill point with gasoline at underground storage temperatures and the vehicle allowed to sit in the sun until a constant fuel temperature was reached. Fuel tank pressure buildup and overflow amounts were recorded, as well as fuel system component and ambient air temperatures.

3.4.2 Attitude Tests. The attitude tests consisted of two separate test series: one involving vehicle pitch and the other involving vehicle rotation around its longitudinal axis (roll-over). The purpose of these tests was to assess the possibility of spillage occurring from the fuel system, including the evaporative emission control devices, when the vehicle comes to rest in an extreme front-up or front-down attitude following an accident or when the vehicle is involved in a roll-over accident. The pitch test conditions were also designed to investigate pitch attitudes which could be encountered during normal driving conditions.

Five representative 1971 automobiles were used for the pitch tests. The vehicle fuel tanks were filled to 90-percent capacity with fuel. The front end of the vehicle was elevated in 15-degree increments until a maximum 60-degree elevation was attained. This procedure was then repeated with the rear end being elevated. Fuel spillage amounts and rates, when they occurred, were measured and recorded.

The roll-over tests were conducted with five vehicles which had been previously front-end barrier crashed, thus following the procedures of the proposed amendment to the Federal Motor Vehicle Safety Standard on Fuel System Integrity, issued in August 1970. The vehicle was rotated 90 degrees around its longitudinal axis until it was resting on its side. Fuel spillage amounts and rates, if any, were measured. The vehicle was then further rotated until it was resting on its top and then on its other side, with any fuel spillage being measured in each attitude.

3.4.3 Component Tests. The primary purpose of this series of tests was to assess the integrity of automotive fuel evaporative emission control subsystems, components, and their attachments in typical automobile crash decelerations. The test series consisted of 10 dynamic tests. Nine tests involved sled runs while the tenth consisted of a drop test. Impact conditions were designed to simulate crash pulses and accelerations imparted to vehicles during 30- and 45-mph impacts.

Six of the sled tests involved complete fuel evaporative emission control subsystems from four different manufacturers. The remaining three sled tests involved vapor storage containers and liquid vapor separators only. All components were mounted on simulated vehicle structure with attachments similar to those used in the actual vehicle. In addition, the components of the subsystem tests were mounted in the same relationship to each other as occurs in the vehicle wherever space on the sled permitted. The orientation of the components on the sled was varied to simulate front, rear, and side impact collisions.

The drop test was conducted with three different carburetors and simulated the accelerations encountered during a front end impact where the engine actually impacts against the struck object.

Acceleration versus time duration was measured for each test. The component and subsystem reactions during the tests were recorded on high-speed film. All of the components and subsystems were examined in detail after the test and evaluated for damage.

3.4.4 Rear-End Barrier Crashes. The primary purpose of these tests was to assess the integrity of the automotive fuel and fuel evaporative emission control systems in rear-end impacts. The test conditions were designed to acquire data relative to the proposed changes to FMVSS 301. The five vehicles used for these barrier tests were previously front-end barrier crashed under other NHTSA programs. The rear structures of these vehicles were undamaged and thus were suitable for conducting the rear-end impact tests.

The vehicle fuel tanks were filled to 90-percent capacity with a suitable solvent. The vehicles were ballasted to the manufacturer's recommended GVW ratings. Impact speeds varied from 20 to 30 mph. Barrier loads and vehicle accelerations were measured and analyzed. High-speed cameras recorded the crash events to facilitate analysis of the fuel system failure modes.

4. FUEL SYSTEM DESIGNS

4.1 GENERAL

All of the evaporative emission control systems studied operate by trapping fuel vapors from the fuel system, storing these vapors, and ultimately burning the vapors in the engine during vehicle operation. The basic components of the system include a sealed fuel tank with some means of pressure-vacuum release, a method of separating the fuel vapors from liquid fuel, a vapor storage container, provisions for admitting air into the system to sweep the trapped vapors into the engine, and associated vapor lines.

The sealed fuel tanks necessitate the incorporation of a liquid fuel expansion space near the fuel tank. American manufacturers use an integral expansion space located within the fuel tank itself, while several foreign manufacturers use a separate expansion tank connected by hoses to the main fuel tank. Shallow fuel tanks, as found in most passenger cars, necessitate the use of a liquid-vapor separator, while deep tanks, such as may be found in station wagons and some pickup trucks, require only proper routing of the vapor vent tube to accomplish liquid-vapor separation.

The design of the liquid-vapor separators varies between manufacturers more than any other component. The two types of separators in most general use are the separate expansion tank mentioned above and a standpipe arrangement that incorporates several vertical vent tubes. Other designs include the use of float check valves and, in one case, a foam baffle assembly.

Pressure-vacuum relief provisions for the fuel tank are generally met by the use of a pressure-vacuum relief valve located either in the fuel filler cap or in the vapor line system. In some cases, however, no particular pressure-vacuum relief provisions are provided and relief must be accomplished through the atmospheric purge air inlet and back through the system to the fuel tank.

Three types of vapor storage containers are in general use. Two of the major American manufacturers utilize the engine crankcase for vapor storage. The other two major American manufacturers and several European manufacturers use a canister containing carbon which adsorbs the fuel vapors on its surface. Several Japanese manufacturers use a metal storage case to contain the vapors until they are routed to the engine.

Although the evaporative emission control systems vary between manufacturers, the systems found in different models of the same manufacturer's vehicles are quite similar. In many cases the only difference is in the location of the components to fit

the particular body style. In other cases minor changes in components occur between different models, but the systems are still basically the same. The following sections describe each manufacturer's design in detail, with differences between various models also being discussed where they occur.

4.2 FORD MOTOR COMPANY

4.2.1 1970 Passenger Cars. The 1970 fuel evaporative emission control system on Ford passenger cars consists of a non-vented fill cap, a fill vent and vapor vents located inside the fuel tank, a fuel tank vent connector assembly running to the liquid-vapor separator, a three-way vent valve, and a carbon canister.

4.2.1.1 Ford Sedans. The Galaxie 400 system is typical of those found in the standard Ford sedans and is shown in Figure 4-1. The fuel tank, which is located just behind the rear axle and approximately 3 feet forward of the rear bumper, contains an extended fill neck with a centrally located fill vent to provide a space for fuel expansion when the tank has been filled to capacity. The fuel tank also contains metal pickup tubes in the corners of the tank to provide venting regardless of the slant of the vehicle. These tubes are connected to a manifold which, in turn, is connected to the fuel tank vent connector assembly.

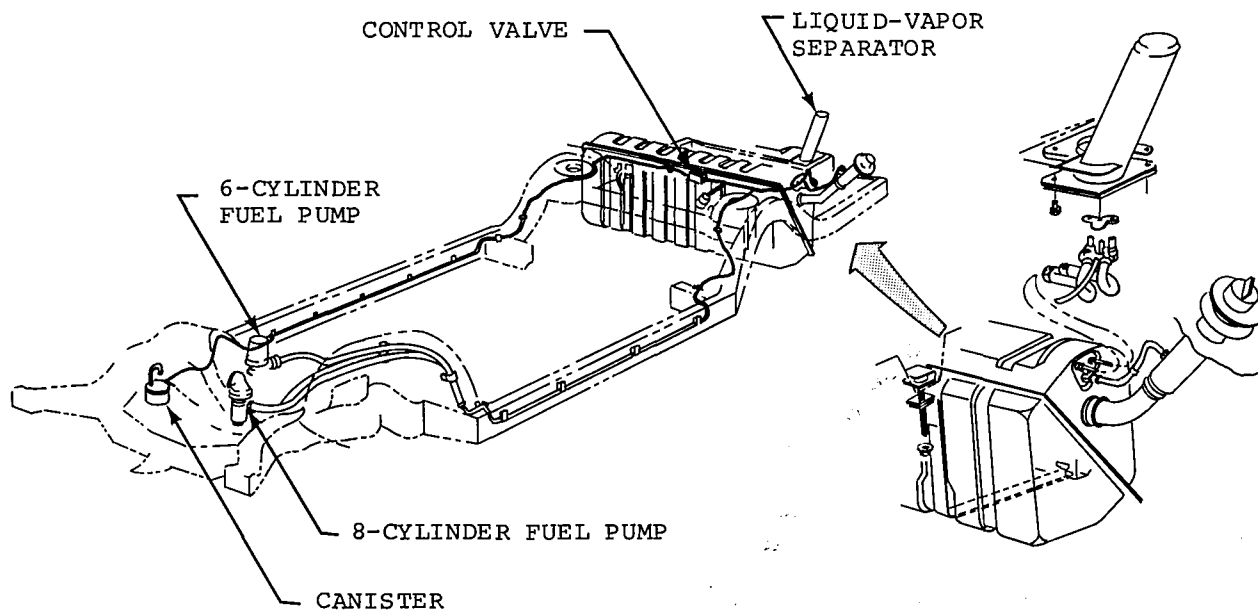


Figure 4-1. 1970 Ford Sedan Evaporative Control System.

The flexible rubber vapor lines from the vent connector assembly on the fuel tank to the liquid-vapor separator are all bonded to a common manifold held in place by one bolt to the separator. The separator itself is a hard plastic cylinder approximately 2-1/2 inches in diameter and 12 inches high. It is mounted in a protected location in the left forward trunk compartment above the fuel tank (Figure 4-2). The installation of the separator above the fuel tank allows the fuel vapor to separate from any liquid fuel rising in the vents.



Figure 4-2. 1970 Ford Galaxie Liquid-Vapor Separator.

Pressure-vacuum relief is provided in the system by means of a three-way control valve in the vapor line. By opening to the atmosphere when necessary, it prevents a vacuum or pressure buildup which might damage the main fuel tank. The valve also helps control the expansion space in the main fuel tank by controlling the flow of vapors from the tank. The valve is mounted to the underside of the vehicle floor near the fuel line outlet from the tank. The valve itself is made of plastic (Figure 4-3) but is well protected by a metal cover installed over the valve.

The flexible line from the liquid-vapor separator to the control valve is attached to the valve by a tight fit only, and is supported by one clamp to the frame between the separator and the valve. The line from the valve to the canister is made of

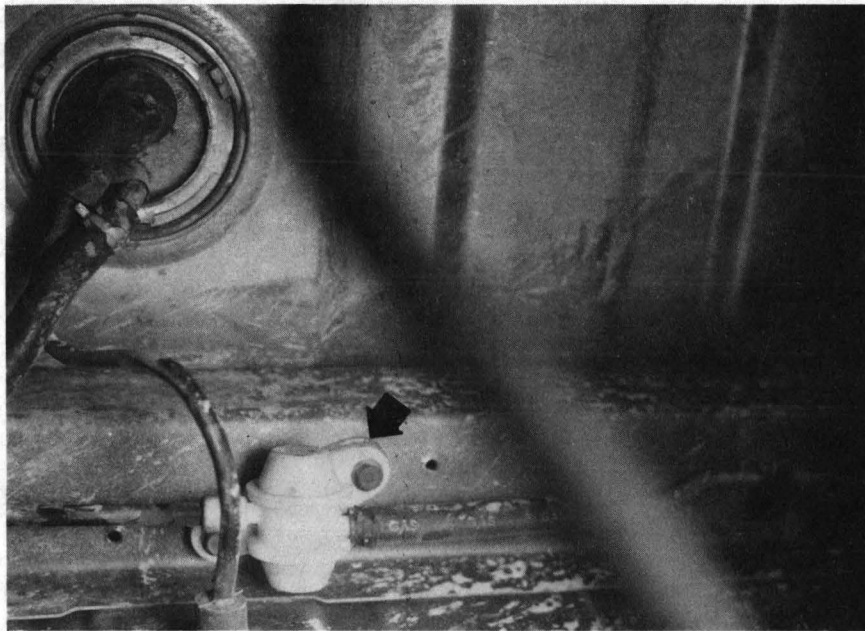


Figure 4-3. 1970 Ford Three-Way Control Valve.

metal with short links of flexible reinforced rubber hose on each end connecting the metal line to each component with spring type hose clamps. This line is routed from the valve (which is located on the driver's side) over to the passenger side, then along the frame to the engine compartment where the canister is located. The line is supported at intervals along its length by clamps attached to the vehicle structure.

The metal canister is located on the right side of the engine compartment and is mounted by means of a bracket to the bottom side of the frame at approximately oil pan level (Figure 4-4). The vapors from the fuel tank enter the canister through the top and are adsorbed on the carbon granules when the engine is not running. When the engine is running, the engine vacuum pulls fresh air into the canister under the bonnet on top to purge the vapors from the carbon and carry them to the carburetor air cleaner (see Figure 4-5).

The purge line from the canister to the air cleaner is made of corrugated reinforced paper (Figure 4-6) and is attached to the canister and air cleaner fittings by a slip fit only. A thin-walled plastic adapter on the side of the air cleaner is used to attach the hose to the cleaner.

The carburetor float bowl is not vented specifically to the fuel evaporative emission control system. The float bowl is

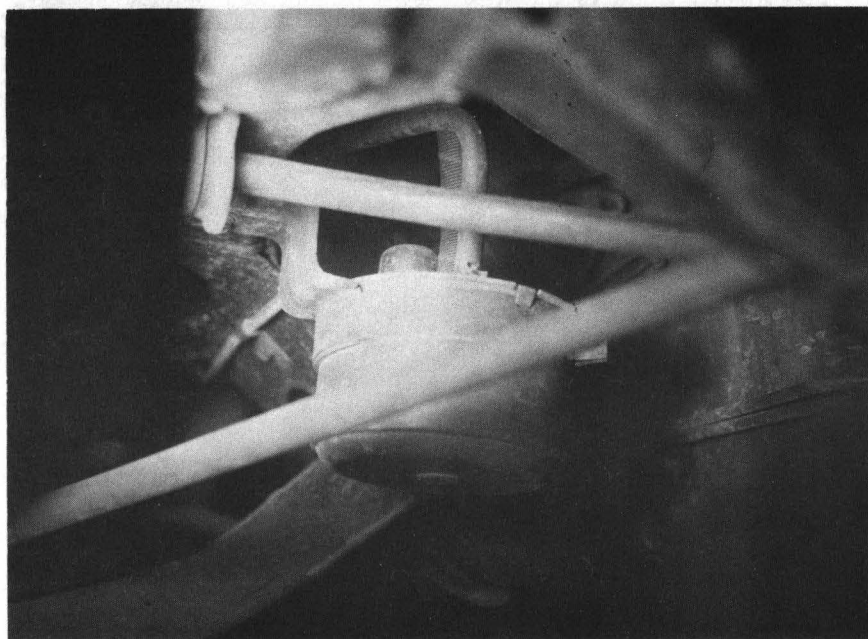


Figure 4-4. 1970 Ford Galaxie Canister.

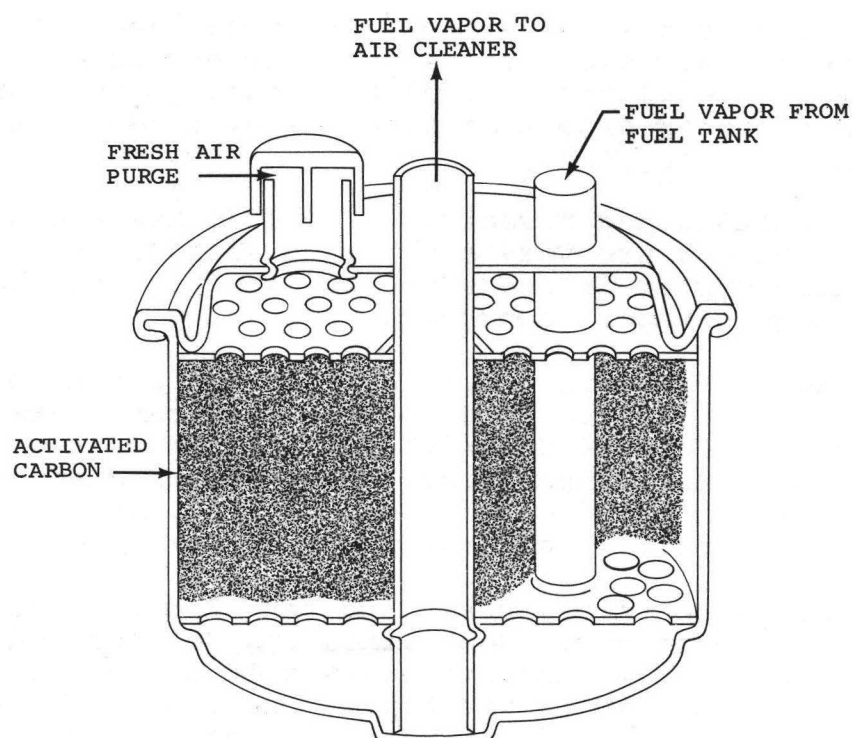


Figure 4-5. Cross Section of Ford Carbon Canister.

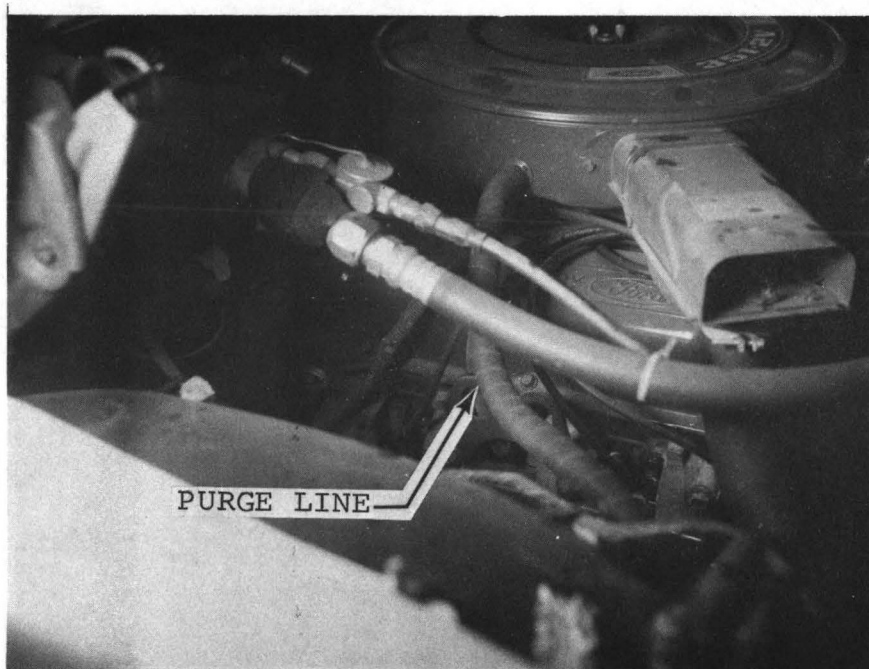


Figure 4-6. Ford Canister Purge Line to Air Cleaner (1970 Galaxie).

internally vented to the carburetor air horn; thus, the vapors will rise into the air cleaner if the vapor pressure is sufficient. The vapors will then travel back through the purge line to the carbon canister or out of the cleaner directly to the atmosphere.

4.2.1.2 Mustang and Maverick. The 1970 Mustang and Maverick fuel systems are very similar to each other and differ from the Galaxie system in the shape and location of the fuel tank and the liquid-vapor separator.

The Mustang and Maverick fuel systems are shown in Figures 4-7 and 4-8, respectively. Both vehicle fuel tanks are located at the extreme rear of the car with the top of the tank forming the floor of the trunk compartment. These tanks also contain fill and vapor vents, as does the Galaxie tank, but the vapor vents within the Maverick and Mustang tanks are made from plastic.

Both vehicles contain double-wing-tank liquid-vapor separators (incorporating vertical vent lines inside) located in the left rear quarter panel. Both vehicles also contain vent connector assemblies located on the top of the fuel tank in the trunk compartment. The Maverick vent connector assembly and liquid-vapor separator are shown in Figures 4-9 and 4-10.

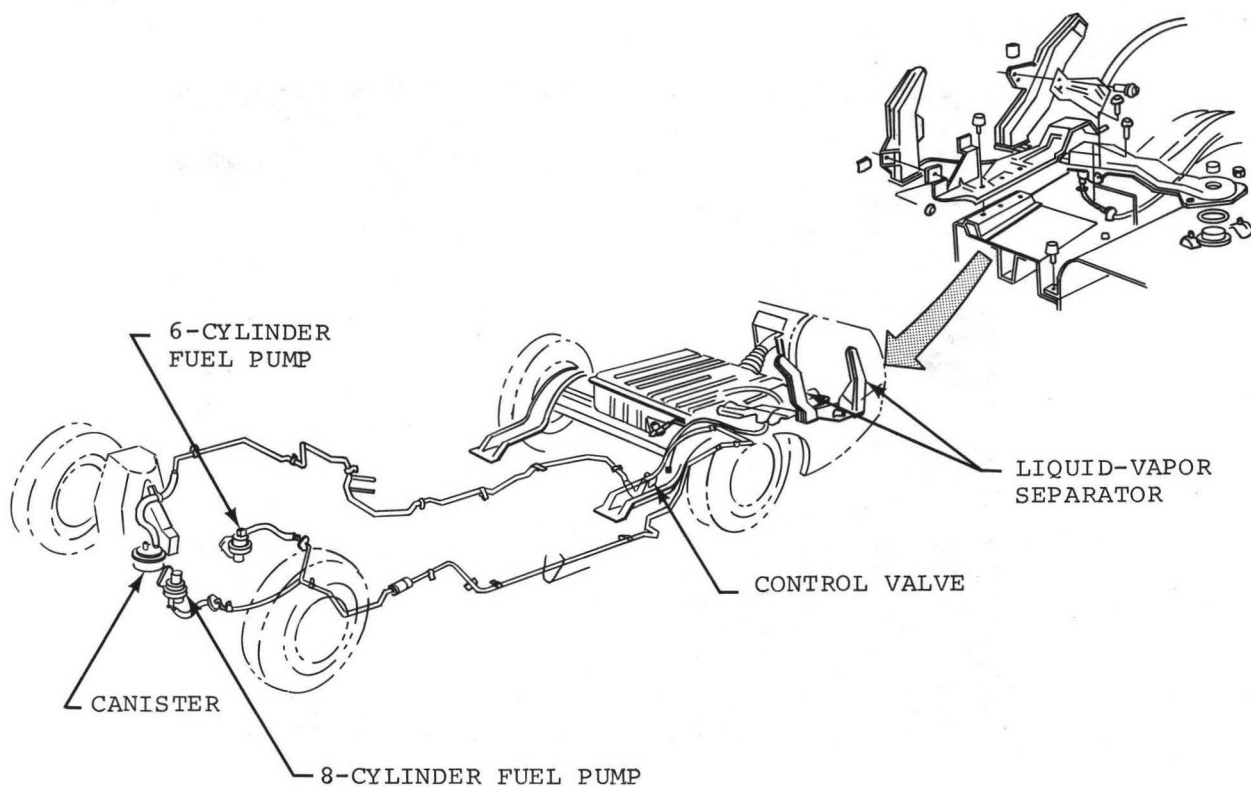


Figure 4-7. 1970 Mustang Evaporative Control System.

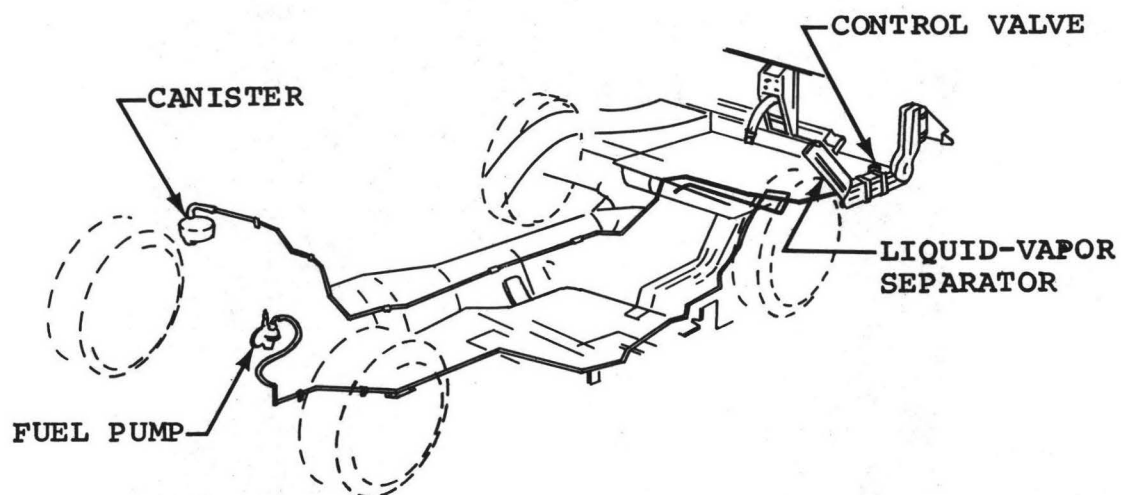


Figure 4-8. 1970 Maverick Evaporative Control System.



Figure 4-9. 1970 Maverick Vent Connector Assembly.



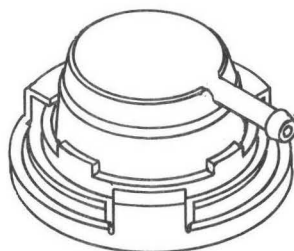
Figure 4-10. 1970 Maverick Liquid-Vapor Separator.

The metal line from the three-way control valve to the carbon canister is routed up the left side of the drive shaft well to the engine compartment in both vehicles. At the firewall the line is routed to the right side of the engine compartment and to the canister, which is identical to the canister in the Ford sedans. The canister in the Mustang is located in the right front part of the engine compartment at oil pan level, while the Maverick canister is located in the right rear part of the engine compartment and is higher, with the top of the canister being almost level with the top of the engine.

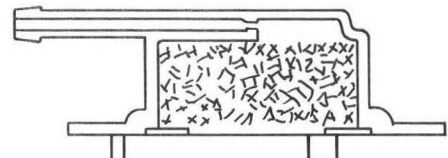
4.2.2 1971 Passenger Cars. The 1971 Ford evaporative emission control system has been considerably simplified from the 1970 version. Major modifications were made to the liquid-vapor separator, the pressure-vacuum relief system, and the fuel tanks in the Mustang, Cougar, Maverick, and Comet.

The fuel tanks for the Mustang, Cougar, Maverick, and Comet are now located under the body floor pan area. On previous models the upper surface of the fuel tanks formed the floor of the trunk. In addition, the internal plastic vent lines have been changed so that these tanks may be cleaned and/or repaired by using standard procedures for steel fuel tanks. Fill limiting is accomplished through the fill neck configuration and/or internal vent lines within the fill neck and tank. The vent system is designed to permit an approximate 10- to 12-percent-volume air space when the tank is filled to capacity. This air space provides for thermal expansion of fuel as well as acting as a manifold for the tank vapor vent system.

All of the Ford passenger cars, including station wagons, now use a liquid-vapor separator which mounts directly to the top of the fuel tank using the same type cam lock ring as the fuel gauging unit. The vapor separator assembly is filled with a foam material which acts as a multiple baffle system to separate the liquid and vapor and retard liquid fuel entrance into the vapor line (see Figure 4-11).



OVERALL



CROSS SECTION

Figure 4-11. 1971 Ford Liquid-Vapor Separator.

The three-way control valve used in the 1970 models has been eliminated in the 1971 models. A pressure-vacuum relief valve has been incorporated in the fill cap to serve the same function as the three-way valve. Fuel system vacuum release is provided in the fill cap valve beyond 1/4 psi and pressure relief beyond 3/4 to 1-1/4 psi.

The rest of the system is essentially the same as that found in the 1970 system. The vapor line from the separator assembly is routed under the car to the metal canister located in the engine compartment. Although the design of the canister is the same as the 1970 canisters, the 1971 canister is shallower and contains only 85 percent of the carbon contained in the 1970 canister. The reinforced paper purge line from the canister to the air cleaner and the plastic adapter at the air cleaner are identical to those found in the 1970 models.

The fuel systems in the 1971 Mustang, Ranchero, and Pinto vehicles are shown in Figures 4-12 through 4-14. These figures show that all of the systems are essentially the same; the only differences being in the size, shape, and location of the fuel tank and filler, the vapor line routing, and the location of the carbon canister.

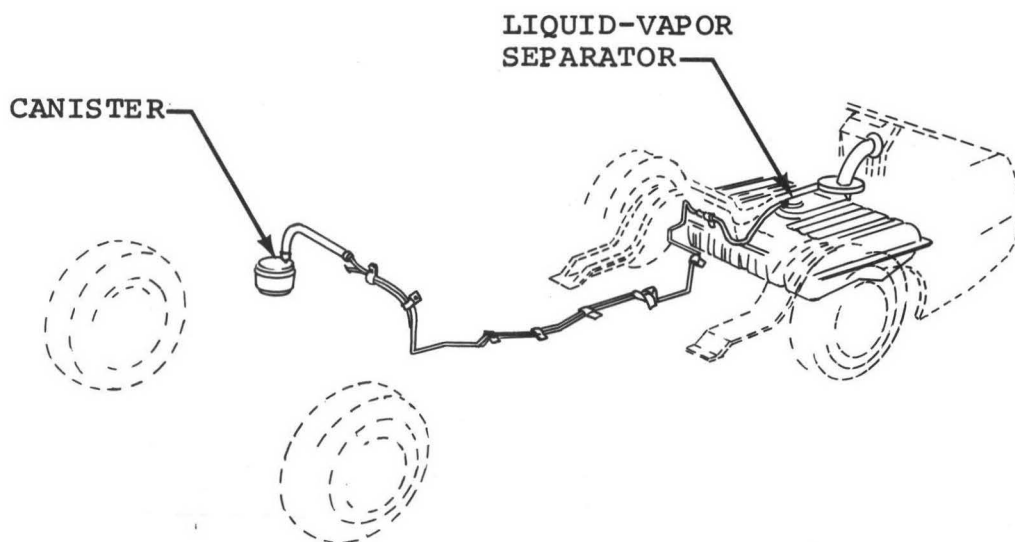


Figure 4-12. 1971 Mustang Evaporative Control System.

The Pinto and the Ranchero both fill from the left rear quarter panel and incorporate long filler tubes attached to the fuel tank by means of flexible couplings. The Mustang fills from

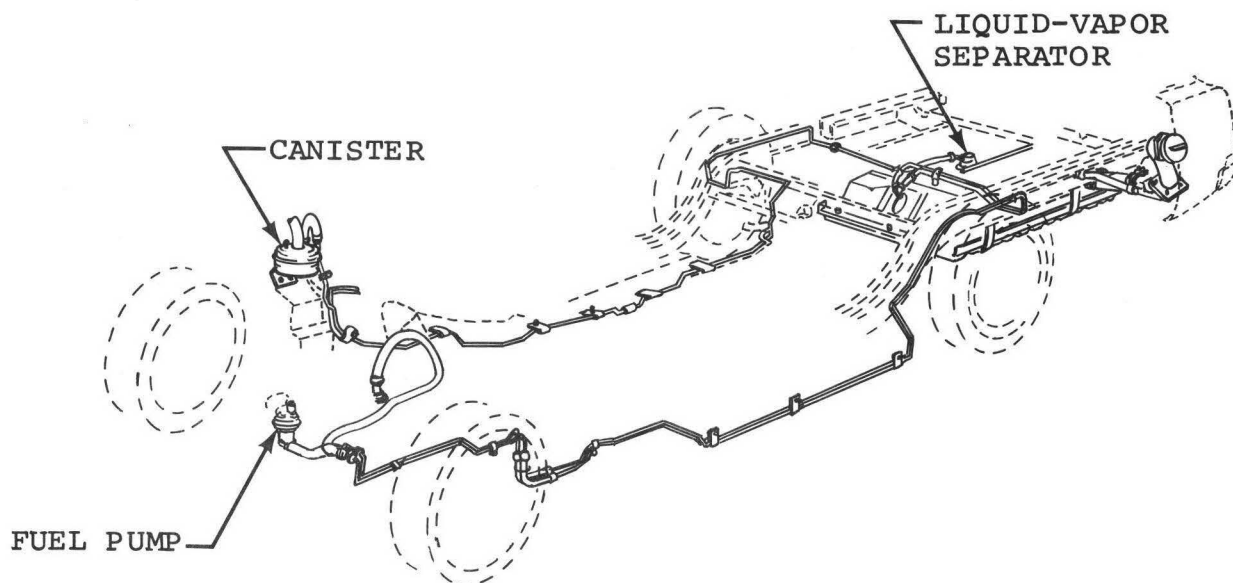


Figure 4-13. 1971 Ranchero Evaporative Control System.

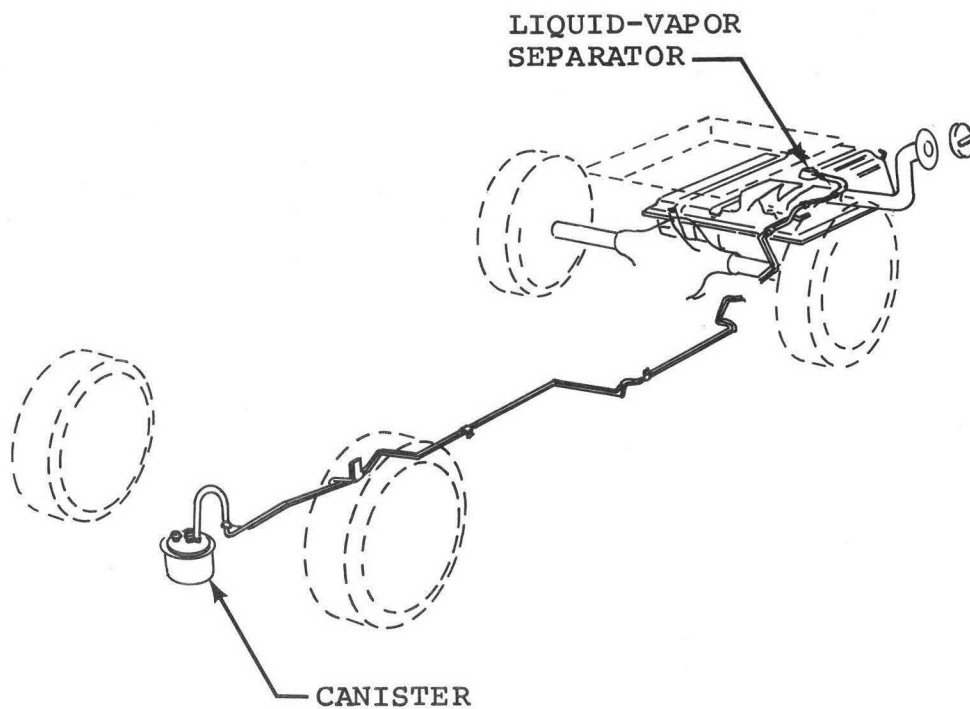


Figure 4-14. 1971 Pinto Evaporative Control System.

the rear and the metal filler neck slip-fits into the fuel tank through a flexible grommet.

The vapor vent lines from the liquid-vapor separator assembly are routed differently in each of the three vehicles. The Ranchero vapor line is routed directly to the right side frame rail and then forward along the frame rail to the carbon canister. The Pinto vapor line is routed directly left and then along the left frame rail to the carbon canister. The Mustang vapor hose is routed forward from the separator and up the right side of the drive shaft well to the canister.

The carbon canister locations also vary. The canisters in the Ranchero and Mustang are located back near the firewall on the right side of the engine compartment, while the Pinto canister is bolted to the front frame on the lower left side of the engine compartment ahead of the engine.

There is one significant difference between the evaporative emission control system in the Pinto and the other passenger cars. The canister vapor purge outlet and the inlet into the air cleaner were originally the same size in the Pinto as in the larger cars. However, Ford recalled all Pintos in March 1971 because of several destructive fires ignited in the air cleaner when the engine backfired. Apparently the vapor flow from the canister to the air cleaner was too large for the Pinto system to handle efficiently. Ford has since installed a metal plug in the vapor hose inlet in the air cleaner to reduce the inlet orifice. This plug is shown in Figure 4-15. The plug has effectively reduced the inlet orifice into the air cleaner from approximately 5/8-inch diameter to 1/8-inch diameter.

4.2.3 1970 One-Half-Ton Pickup Trucks. The 1970 Ford F-100 pickup truck evaporative emission control system is shown in Figure 4-16. The system consists of a sealed fuel tank, a vapor separator tank, vapor emission control valve assembly, vapor vent tubes, and a carbon canister.

The fuel tank is located in the passenger compartment behind the seat. The tank is filled through the filler located on the left side of the vehicle just behind the left door. The non-vented fill cap protrudes outside the vehicle structure approximately 1 to 1-1/2 inches. The filler neck is approximately 10 inches long, including the connector from the filler to the tank. This connector consists of a rubber hose connected on both ends to the metal filler tubes with screw type clamps as shown in Figure 4-17. Over-filling is prevented by the emission control valve in conjunction with the extended filler neck and its integral vent tube.

Two metal vapor lines exit the top of the tank, one from each side, and are routed to the liquid-vapor separator as shown

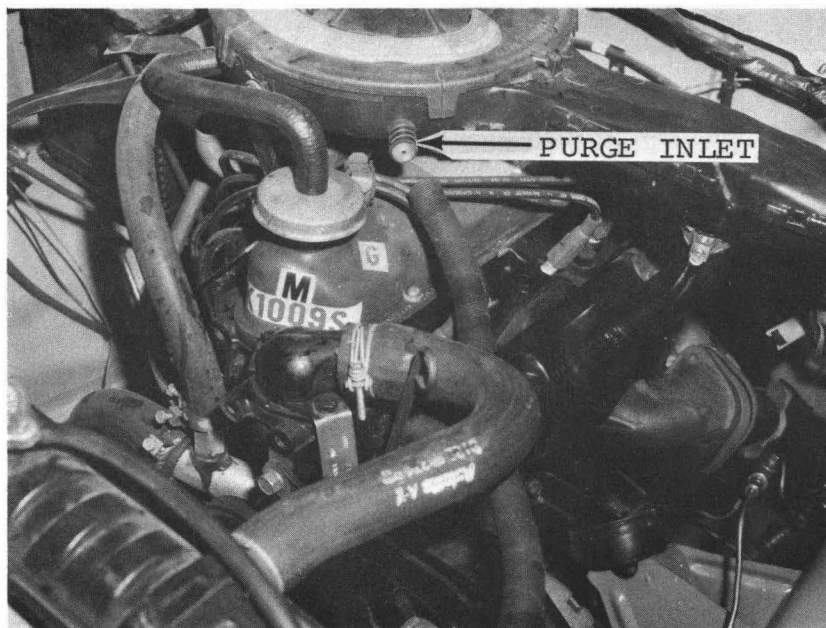


Figure 4-15. 1971 Pinto Air Cleaner Purge Inlet (with purge hose removed) Showing Flow-Limiting Plug.

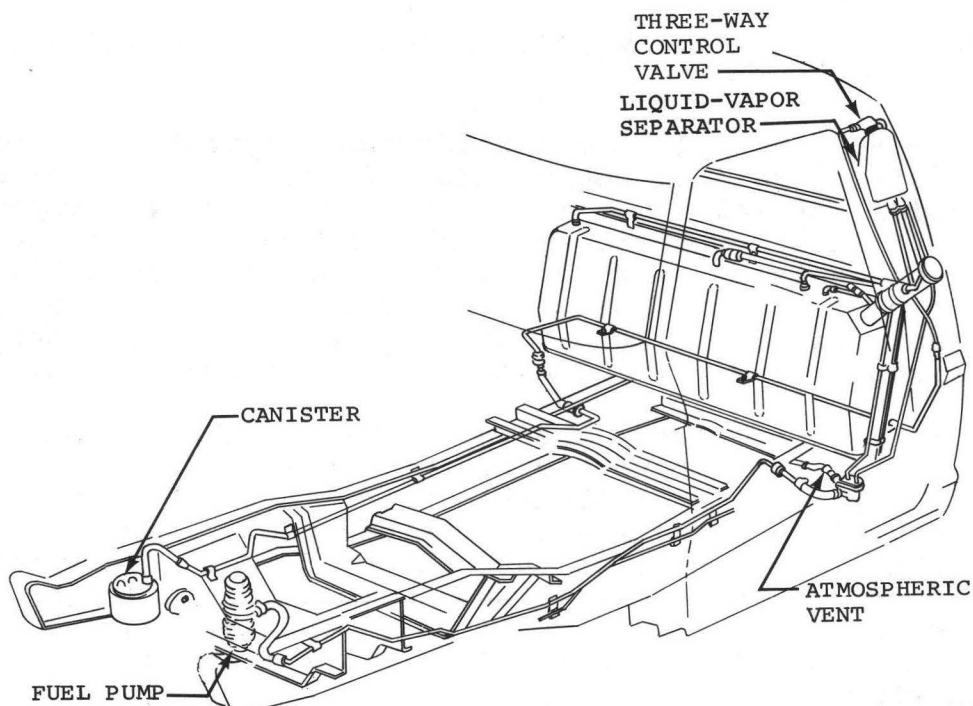


Figure 4-16. 1970 Ford F-100 Pickup Truck Evaporative Control System.

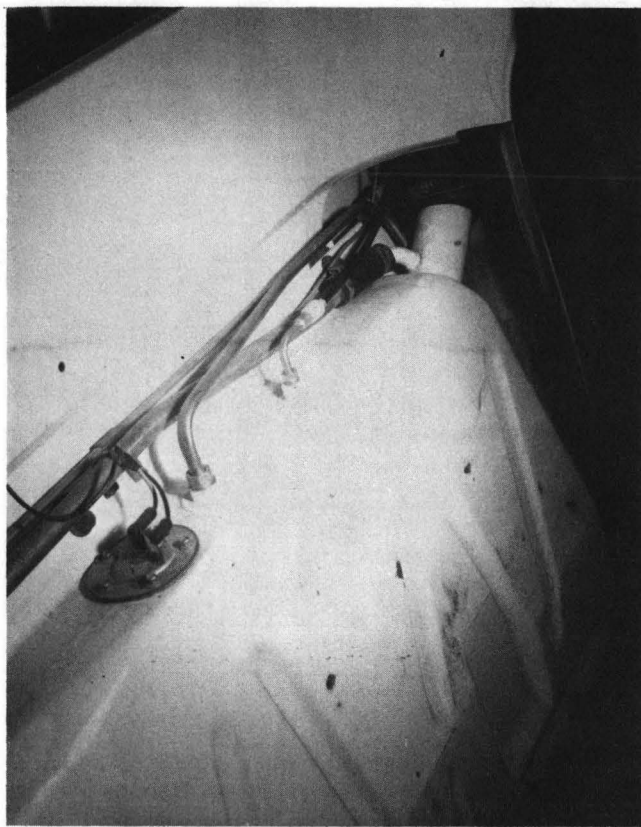


Figure 4-17. 1970 Ford F-100 Fuel Tank and Filler.

in Figure 4-18. The plastic liquid-vapor separator is located in the cab structure just behind the left door. A three-way vapor emission control valve is mounted on top of the vapor separator tank. An atmospheric vent tube and a vapor tube leading to the carbon canister exit the valve. The valve assembly controls the flow of vapors, provides fuel tank ventilation, and controls the maximum fuel tank refill capacity in conjunction with the extended fuel filler neck and its integral vent.

The vapor line between the separator and the canister consists of a metal tube connected to the canister and to the separator with short links of flexible hose. A short section of flexible reinforced hose is also incorporated in the line under the floor where the line goes through the frame. The vapor line is routed down behind the fuel tank, across the passenger compartment to the right side, then forward and through the floor, back inboard to the frame, and up the right frame rail to the carbon canister.

The metal canister is the same type as those used in Ford passenger cars. It is mounted to the frame in the right forward

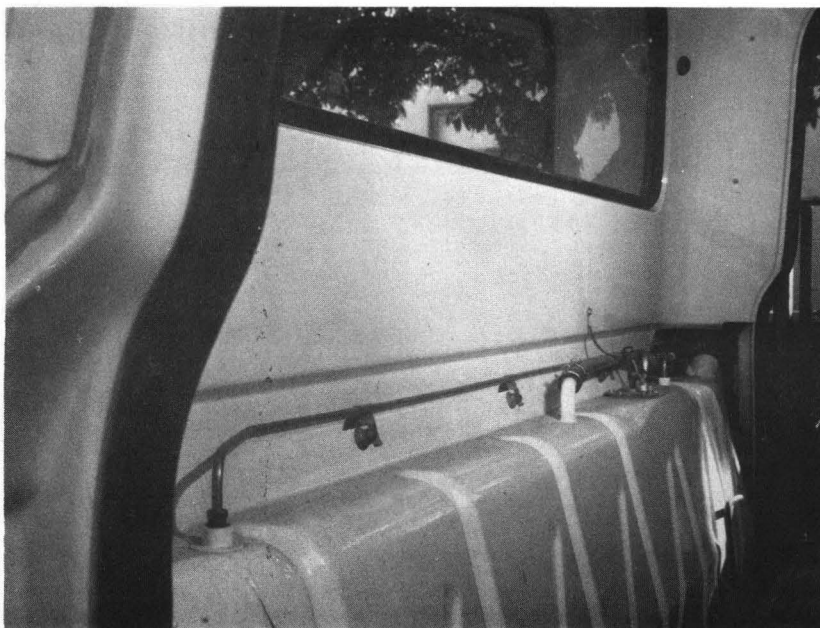


Figure 4-18. 1970 Ford F-100 Fuel Tank and Vapor Vent Lines.

section of the engine compartment. A reinforced paper hose, such as is found in the passenger cars, serves as the purge line and runs from the canister to the air cleaner.

4.2.4 1971 One-Half-Ton Pickup Trucks. Although a 1971 Ford pickup truck was not inspected, the Ford truck shop manual shows that the fuel evaporative emission system on the F-100 vehicle has been considerably simplified (Figure 4-19). The liquid-vapor separator tank with the vapor emission control valve has been eliminated. The 1971 system uses a U-shaped steel tube as the vapor vent chamber. Liquid fuel is prevented from entering the vapor line by a 0.050-inch orifice included in the U-shaped vapor vent chamber. Fuel vapors are conducted from the vent chamber through a vapor line to the carbon canister located in the engine compartment.

4.3 GENERAL MOTORS CORPORATION

4.3.1 1970 Passenger Cars

4.3.1.1 Chevrolet Sedans. The evaporative emission control system used in the 1970 Chevrolet sedans is shown in Figure 4-20. This system consists of three basic components: a sealed fuel tank, a liquid-vapor separator, and a carbon canister.

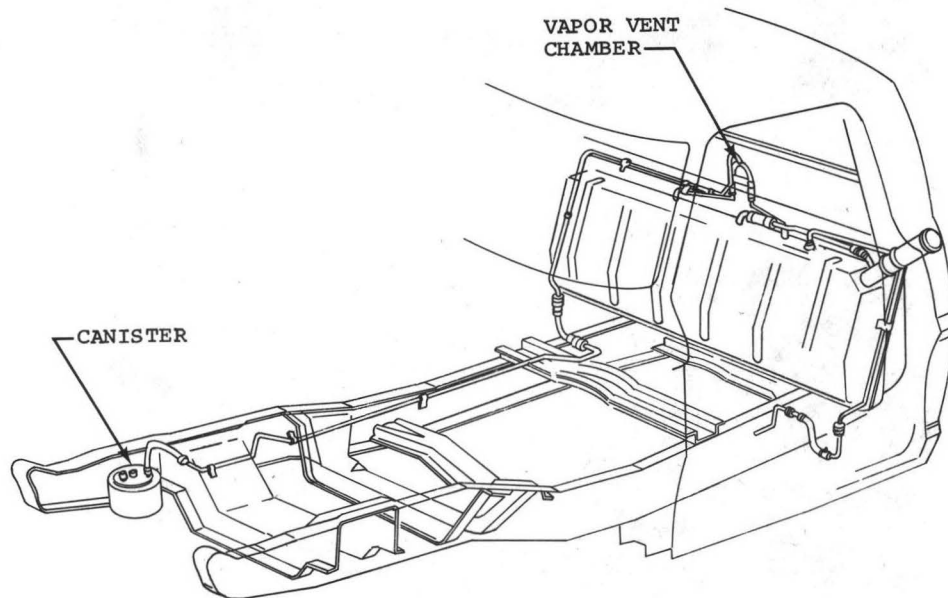


Figure 4-19. 1971 Ford F-100 Pickup Truck Evaporative Control System.

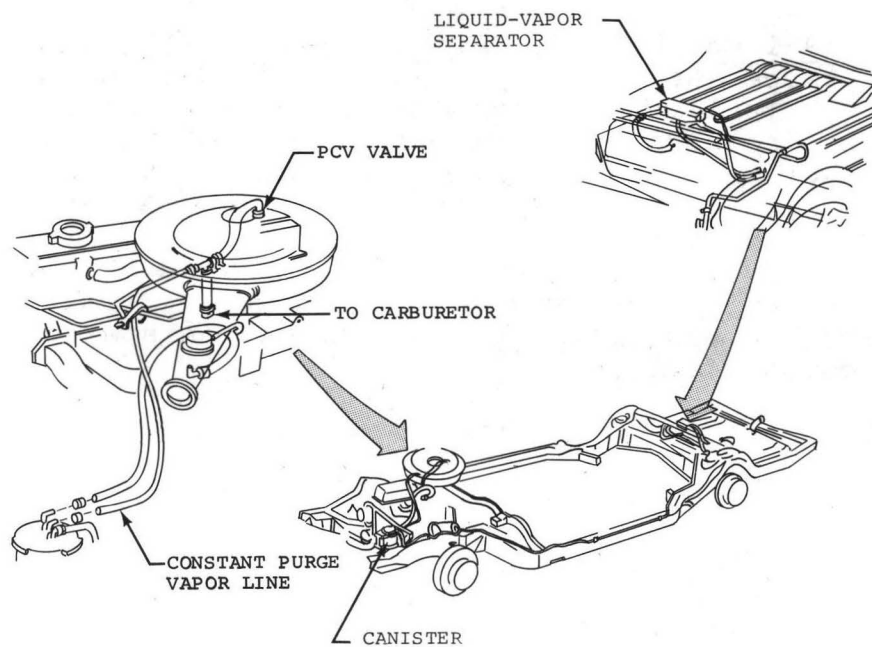


Figure 4-20. 1970 Chevrolet Evaporative Control System.

The metal fuel tank contains a fill limiting baffle that controls air as the tank is filled to provide for later volume increases due to thermal expansion (Figure 4-21). Three vents are incorporated in the fuel tank to collect the vapors. The vents are positioned so that one is always above the liquid at any vehicle attitude. The fuel tank is located under the body floor at the rear of the vehicle. The metal filler neck, located between the fuel tank and rear bumper, is soldered into the tank fill opening. The filler cap incorporates a pressure-vacuum relief valve to prevent large pressure differentials which might damage the fuel tank.

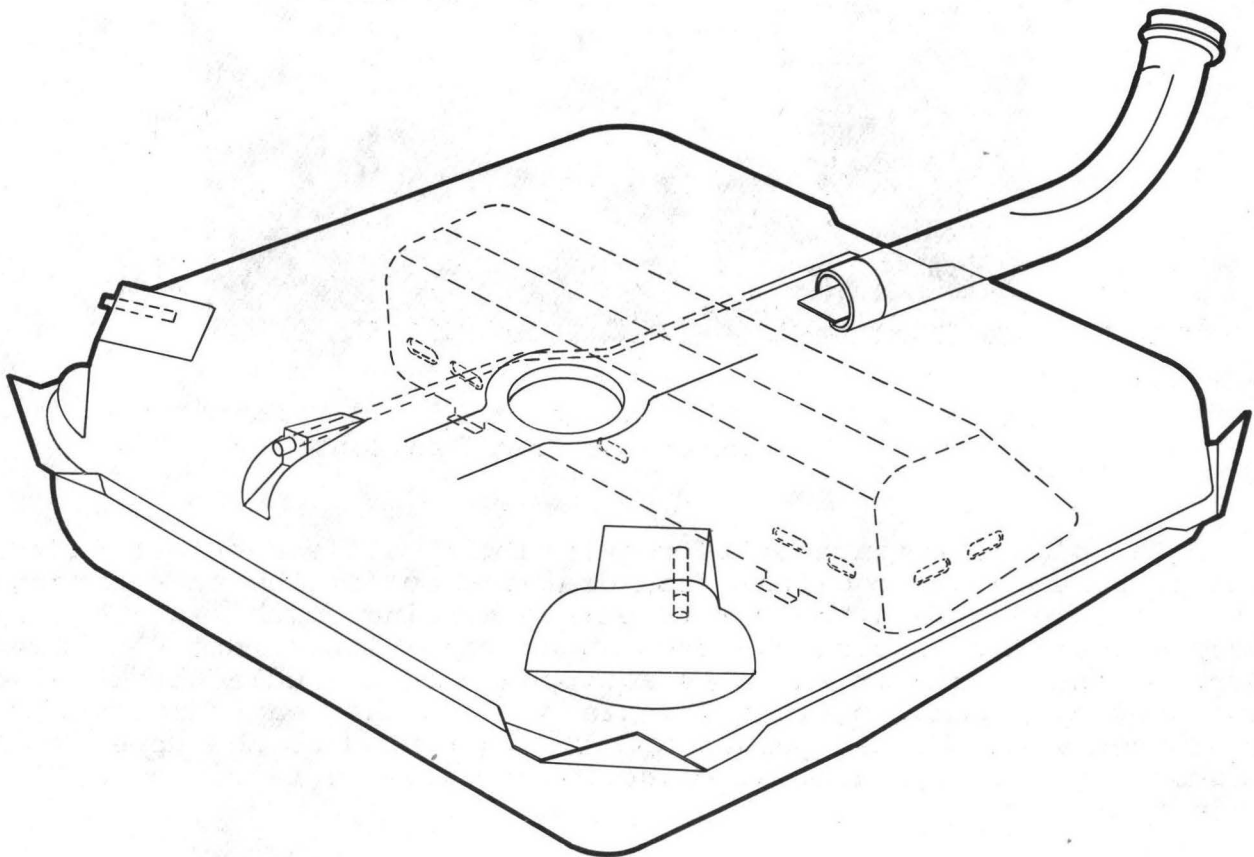


Figure 4-21. 1970 Chevrolet Evaporative Control System Fuel Tank.

A liquid-vapor separator, which is connected to the fuel tank vapor vents, is mounted to the underbody in the kick-up area just ahead of the fuel tank. The vapor lines from the two forward tank vents are made of metal and are connected to the tank and to the separator with short links of rubber hose. The entire

vapor line from the center vent is made of hose. Figure 4-22 shows the separator and the connecting hoses.



Figure 4-22. 1970 Chevrolet Liquid-Vapor Separator Installation.

The plastic separator is required with all sedan fuel tanks. Its purpose is to stop fuel from draining out of the tank through the front vents when the car is parked heading downhill. This is accomplished by routing the front vent vapor lines into the lower part of the separator which is equipped with a needle check valve actuated by a plastic float (Figure 4-23). The rear tank vent, submerged when the car points uphill, is routed to the upper chamber of the separator since no check valve is required for this vent.

A vapor line exits the top chamber of the separator and is routed forward to the carbon canister located in the engine compartment. This line is made of metal and is connected to the separator by a short link of flexible reinforced rubber hose. The metal line is routed under the floor of the car to the left side frame rail. The line follows the frame to the engine compartment where it makes a 90-degree upward turn and attaches to a rubber hose leading to the canister. The line is clamped to the frame at regular intervals.

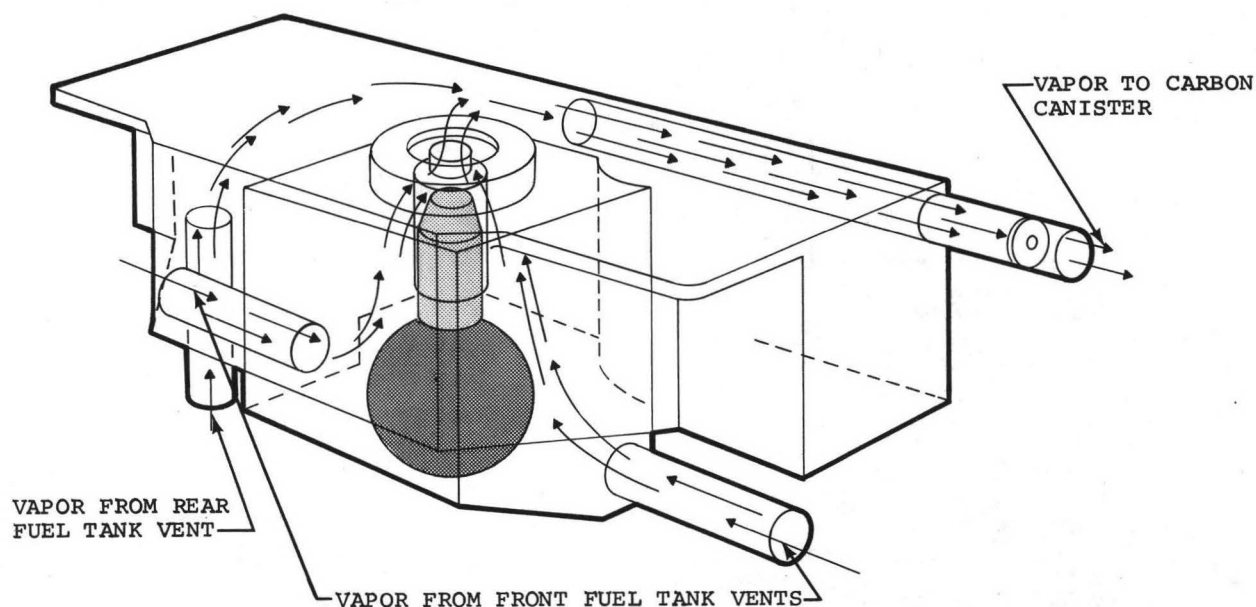


Figure 4-23. 1970 Chevrolet Liquid-Vapor Separator.

The plastic canister is mounted to the left forward wall of the engine compartment with a circular metal strap. The amount of vapors generated at the carburetor and the ability of the engine to consume vapors removed from the charcoal canister vary from engine to engine, thus requiring two different purge systems.

All 6-cylinder and 2-barrel V-8 engines use a variable purge system with the carbon canister shown in Figure 4-24. The fuel vapor enters the canister through a small cylindrical chamber above the carbon. When the engine is running, most vapor is immediately drawn off by manifold vacuum through a .034-inch-diameter orifice in the canister center section. The constant purge line from this connection is joined to the PCV carburetor hose by means of a T connection as shown in Figure 4-20. Excess vapor is trapped by the activated carbon. When engine speed is above idle, air is drawn upward through the carbon where it picks up the adsorbed vapors and then through the variable purge line to the air cleaner snorkel.

Four-barrel carburetors use a staged purge system similar in operation to that described above. However, the variable purge in this system is regulated by a ported vacuum signal from the carburetor to the canister purge valve. All vapors are routed to the PCV hose and then into the carburetor. The hose routing for the staged purge system is shown in Figure 4-25 and the system is shown schematically in Figure 4-26.

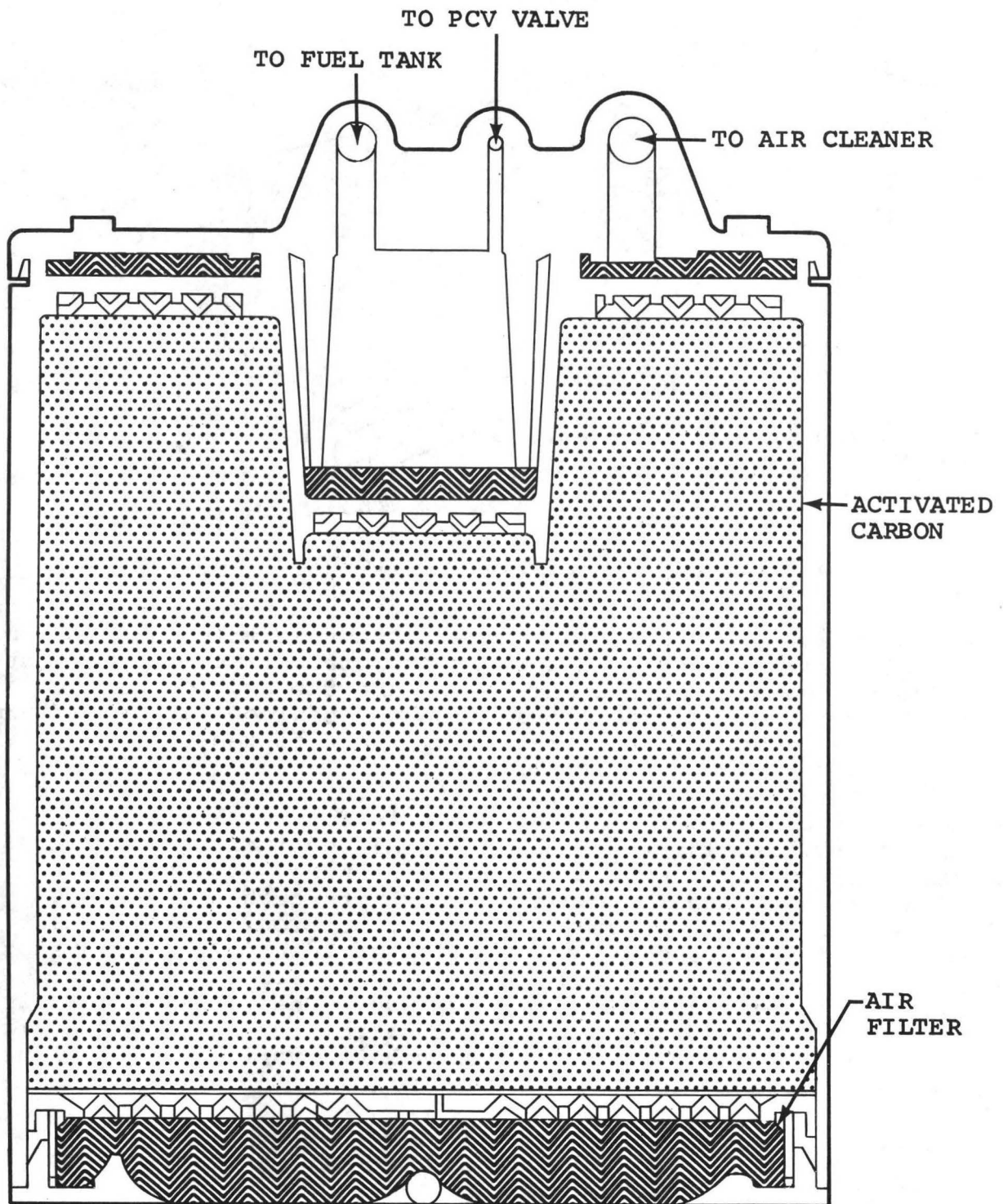


Figure 4-24. Chevrolet Carbon Canister for Variable Purge System.

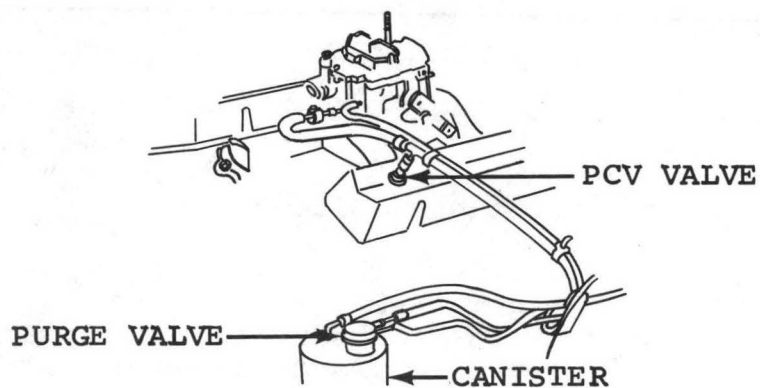


Figure 4-25. Chevrolet Vapor Hose Routing for Staged Purge System.

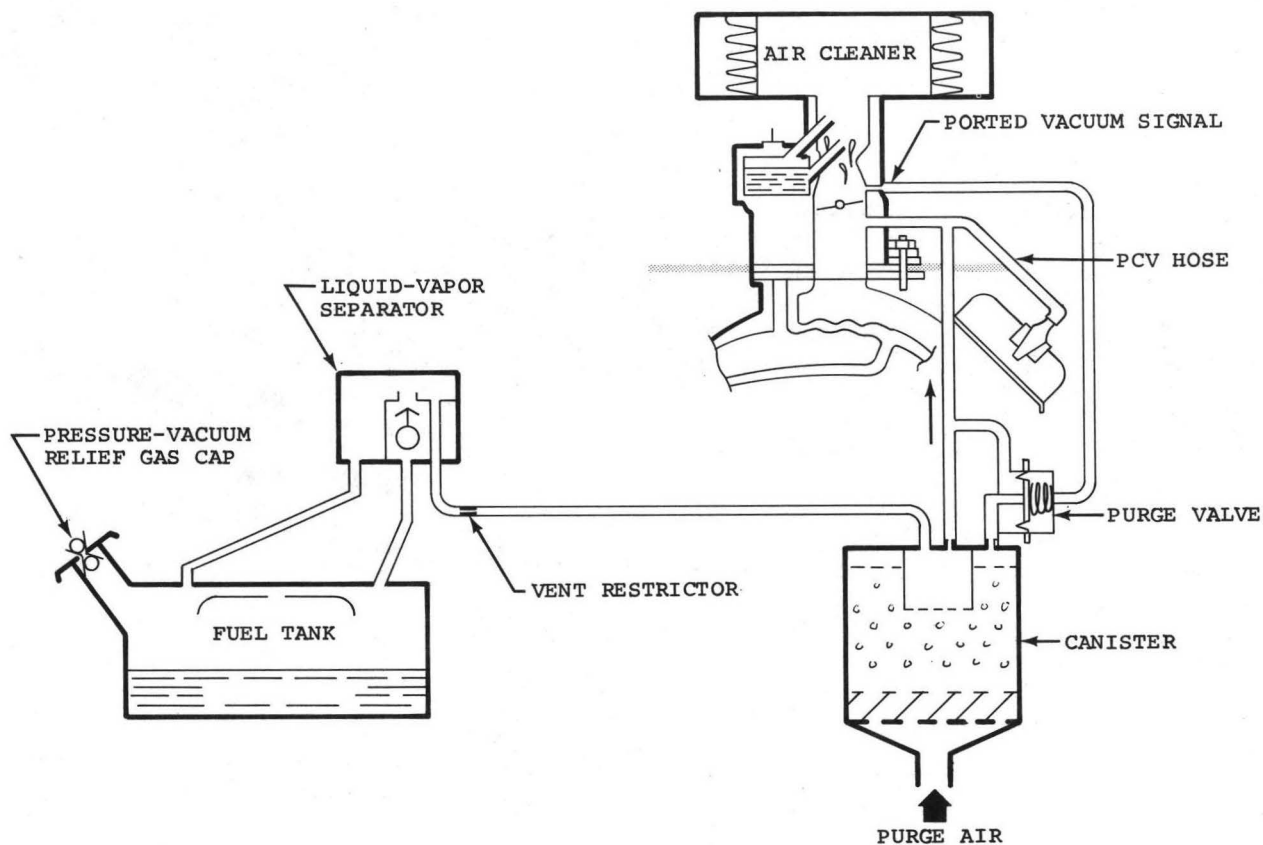


Figure 4-26. Chevrolet Staged Purge System.

All carburetor float bowls are internally vented and the trapped vapors are stored in the intake manifold, air cleaner, and canister lines.

The evaporative control system does require periodic canister filter servicing. Every 12 months or 12,000 miles, whichever occurs first (more often under dusty conditions), the filter in the base of the canister must be replaced.

4.3.1.2 Oldsmobile Sedans. The 1970 Oldsmobile evaporative control system, shown in Figure 4-27, is very similar to the 1970 Chevrolet system as it contains the same type of fuel tank, filler cap, liquid-vapor separator, and carbon canister as does the Chevrolet system. There are several minor differences, however, between the two systems.

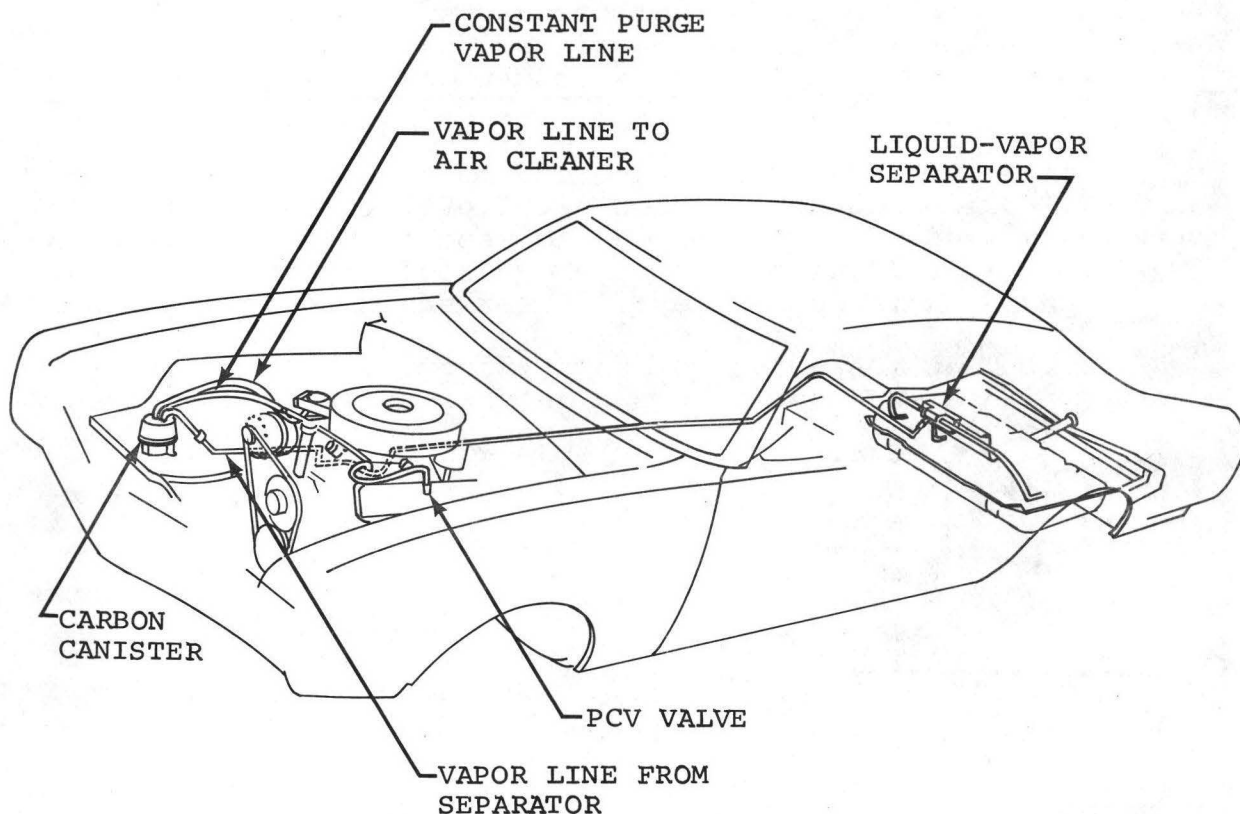


Figure 4-27. 1970 Oldsmobile Evaporative Control System.

Figure 4-27 shows that the vapor hose in the Oldsmobile is routed up the right side frame rail to the canister rather than the left side as in the Chevrolet. This occurs on all cars except the Toronado and those cars containing the L-6 engine (F-85

and Cutlass). The vapor line in these vehicles is routed up the left side as in the Chevrolet.

The carbon canisters are located on the right front fender filler panel on all cars except the L-6 engine models and the Toronado, which are on the left. Only the variable purge system described for the Chevrolet is used in the Oldsmobile system. This system consists of the canister (without the purge valve), the constant purge line from the canister to the PCV line, and the variable purge line from the canister to the air cleaner.

4.3.1.3 Pontiac Sedans. The 1970 Pontiac evaporative emission control system, shown in Figure 4-28, is also very similar to the Chevrolet system. The fuel tank contains an internal fill-limiting chamber and internal vents very similar to those found in the Chevrolet tank. In addition, the same type of liquid-vapor separator is used in the Pontiac as in the Chevrolet.

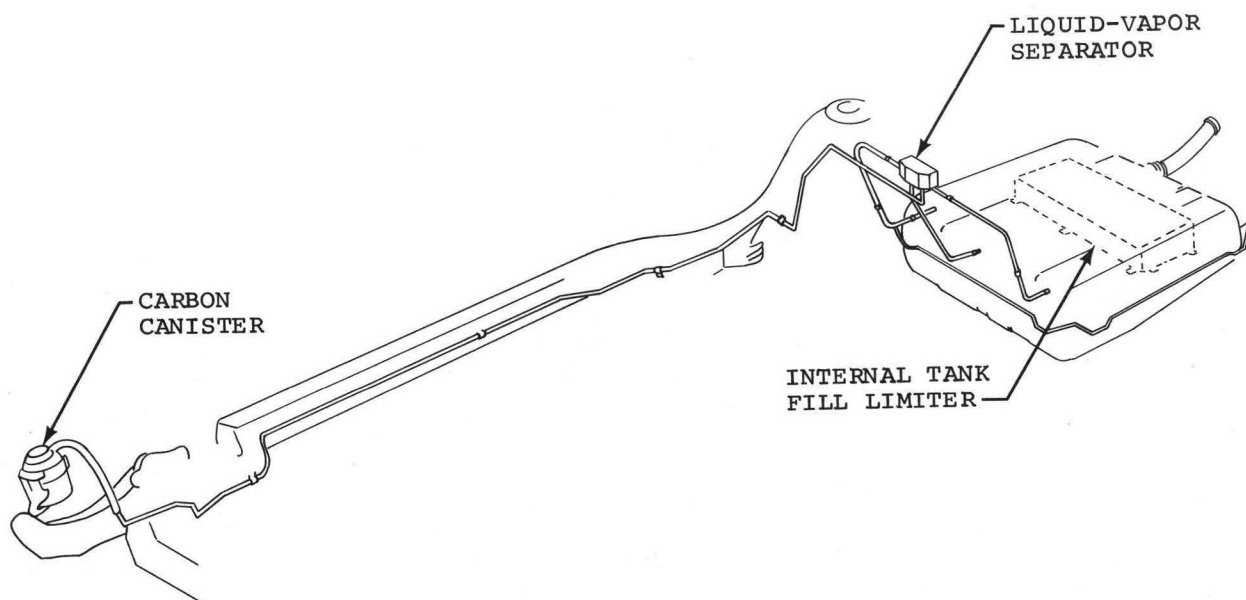


Figure 4-28. 1970 Pontiac Evaporative Control System.

The vapor line from the liquid-vapor separator is routed along the right side frame rail to the carbon canister. The canister is mounted on the engine side of the radiator support baffle assembly and is located on the side of the car opposite the battery (right side for V-8 engines and left side for 6-cylinder engines). A crossover pipe is routed along the back of the engine compartment to reach the canister mounted on the left side of the 6-cylinder cars.

The carbon canister used in the Pontiac is similar to that used in the Chevrolet except that it contains a demand valve mechanism incorporated in the top of the canister which controls the pressure-vacuum relief provisions of the entire Pontiac system. (The filler cap does not contain a pressure-vacuum relief valve.) This valve mechanism is shown in Figure 4-29. The vapor regulator valve in the canister opens when the vapor pressure from the fuel tank rises, allowing the vapors to enter the canister. A separate vacuum-relief valve allows inward air flow into the vapor vent system and fuel tank under negative pressure conditions. When the engine is running, air is drawn in through the bottom of the canister, sweeping the vapors into the purge hose leading to the carburetor.

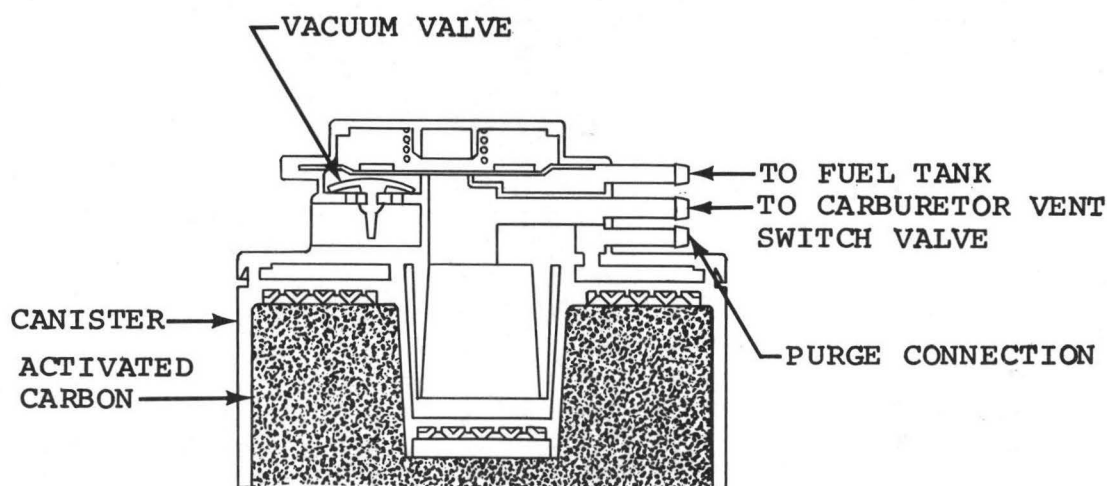


Figure 4-29. Pontiac Canister and Valve Assembly.

Two purge ports are provided in the carburetor. One operates whenever the engine is running to handle any vapors from the tank and to provide a slight purge of the canister. The other port, which is closed at engine idle, opens above idle to provide further purge of the carbon. A vent switch valve in the carburetor is closed when the engine is running but opens when the engine is shut off to allow vapors from the carburetor bowl to travel to the canister where they are adsorbed by the carbon.

4.3.1.4 Station Wagons. The Chevrolet station wagon differs from the sedans in the shape and location of the fuel tank and the absence of a liquid-vapor separator. The station wagon fuel tank is vertically mounted in the left rear quarter panel with the filler centered near the extreme top of the tank. Because of the vertically mounted fuel tank, no liquid-vapor separator is necessary and the vapor line from the tank to the

canister is welded directly to the top center of the fuel tank. The location of the vapor line outlet at the top of the tank assures that it is above the liquid fuel level during all operating attitudes of the vehicle.

The metal vapor line is routed down the forward side of the fuel tank and connected to a rubber hose with a spring type clamp, as shown in Figure 4-30. The hose is routed through a hole in the frame and is connected to a metal vapor line leading to the canister. The vapor line is routed to the canister along the left frame rail as in the sedans. The rest of the evaporative emission system is identical to that found in the sedans.

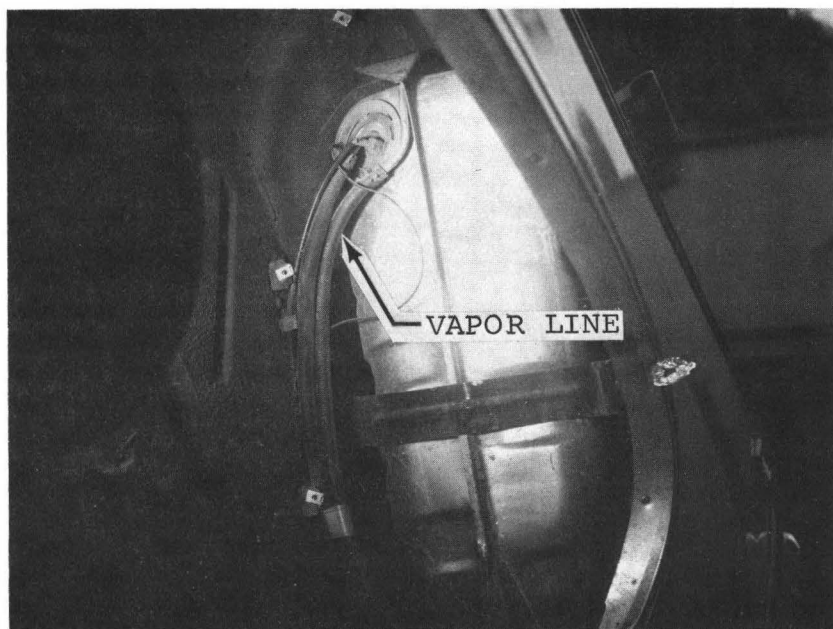


Figure 4-30. 1970 Chevrolet Station Wagon Fuel Tank and Vapor Vent Line.

The Oldsmobile and Pontiac stations wagons are also characterized by the vertically mounted tank in the left rear quarter panel and the absence of a liquid-vapor separator. The remainder of the evaporative emission control systems are identical to the respective sedan systems.

4.3.2 1971 Passenger Cars

4.3.2.1 Chevrolet Sedans. The 1971 Chevrolet evaporative emission control system incorporates several major changes from that found in the 1970 models. Although all of the components in

the 1971 systems remain in their respective locations compared to the 1970 models, several of the components themselves have been changed.

A significant change has been in the area of fuel fill. The 1971 designs use filler necks which extend to the midpoint of the fuel tank to limit the degree of fill, rather than using integral fill limiting tanks. The fuel tanks, however, still contain the same system of internal vapor vents. The fuel tank filler cap still contains a pressure-vacuum relief valve, but the cap has been changed to a deep shell type incorporating two sets of locking tangs. This creates a two-step removal and installation procedure for the filler cap.

The liquid-vapor separator has been completely changed from the 1970 separator. The 1971 separator consists of a metal stand-pipe assembly mounted behind the rear seat (forward and above the gasoline tank). The separator and connecting hoses are shown in Figure 4-31, while Figures 4-32 and 4-33 show the placement of the separator and the tank-to-separator hoses, respectively.

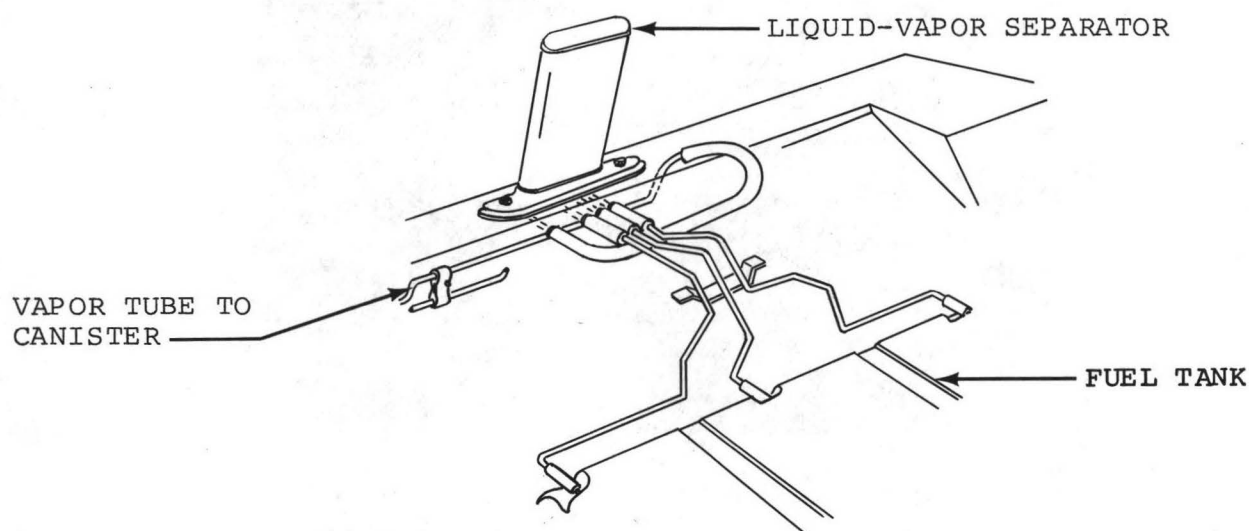


Figure 4-31. 1971 Chevrolet Liquid-Vapor Separator.

The vapor hose from the liquid-vapor separator to the carbon canister is routed up the left side frame rail as in the 1970 models. The carbon canister, which is essentially the same as that found in the 1970 Chevrolets, is mounted in the left forward part of the engine compartment. As in the 1970 models, either a variable purge or a staged purge system with the appropriate canister is used to conduct vapors from the canister to the carburetor. The particular system to be used depends on the type of engine and the type of carburetor in the vehicle.

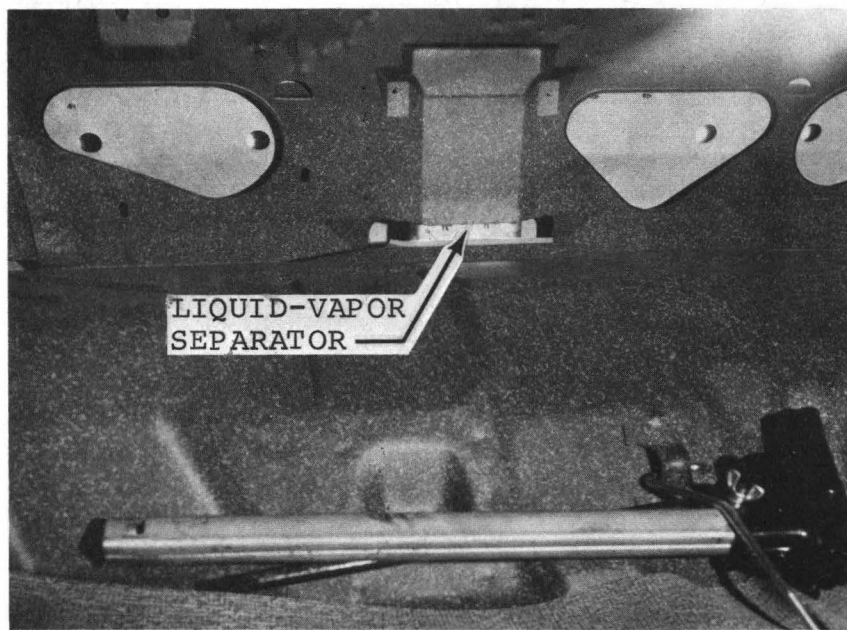


Figure 4-32. 1971 Chevrolet Liquid-Vapor Separator Installation.

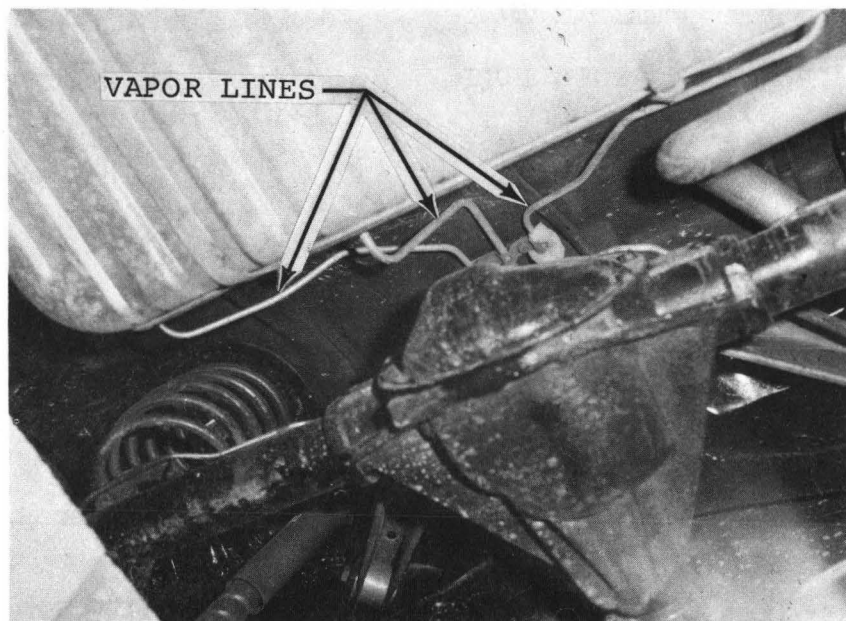


Figure 4-33. 1971 Chevrolet Vapor Lines From Fuel Tank to Liquid-Vapor Separator.

4.3.2.2 Oldsmobile Sedans. Changes similar to those made in the 1971 Chevrolet system have also been made in the 1971 Oldsmobile system. The extended filler neck in the fuel tank, the two-step locking filler cap, and the standpipe liquid-vapor separator are all incorporated into the 1971 Oldsmobile system. These components are identical to those used in the Chevrolet system.

Several other changes have been made in the 1971 Oldsmobile systems. Whereas the vapor line from the separator to the carbon canister was routed up the right side frame rail in all 1970 Oldsmobiles, except the Toronado and those containing the L-6 engine, the vapor line in the 1971 larger Oldsmobiles (Delta 88 and Ninety-Eight) is routed up the left side frame rail, as may be seen in Figure 4-34. When the canister is mounted on the left side of the engine compartment, as it is for all V-8 engines, a vapor cross-over pipe is routed from the left to right side in the forward part of the engine compartment. The canister is still located in the left front part of the engine compartment for all 6-cylinder cars and for the Toronado.

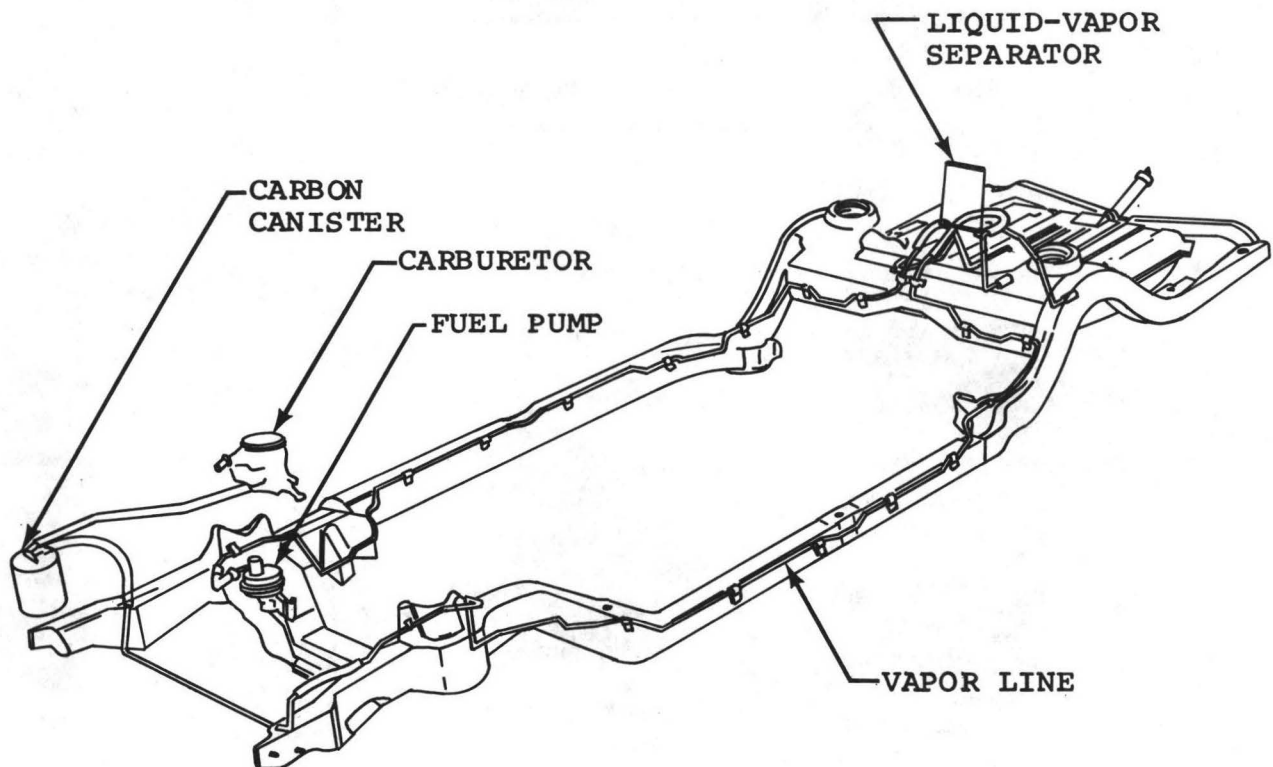


Figure 4-34. 1971 Oldsmobile Evaporative Control System (Delta 88 and Ninety-Eight).

The carbon canister in the Oldsmobile has also been changed from the 1970 to the 1971 models. All 6-cylinder engines now use the General Motors staged purge canister with the purge valve. All V-8 engines use a constant purge canister which contains only one outlet for a purge line which runs directly to the carburetor.

4.3.2.3 Chevrolet Vega. The 1971 Chevrolet Vega utilizes the same type of fuel evaporative emission control system as do the larger Chevrolet passenger cars. The Vega system, shown in Figure 4-35, consists of a sealed fuel tank, a pressure-vacuum relief filler cap, a standpipe liquid-vapor separator, and a carbon canister.

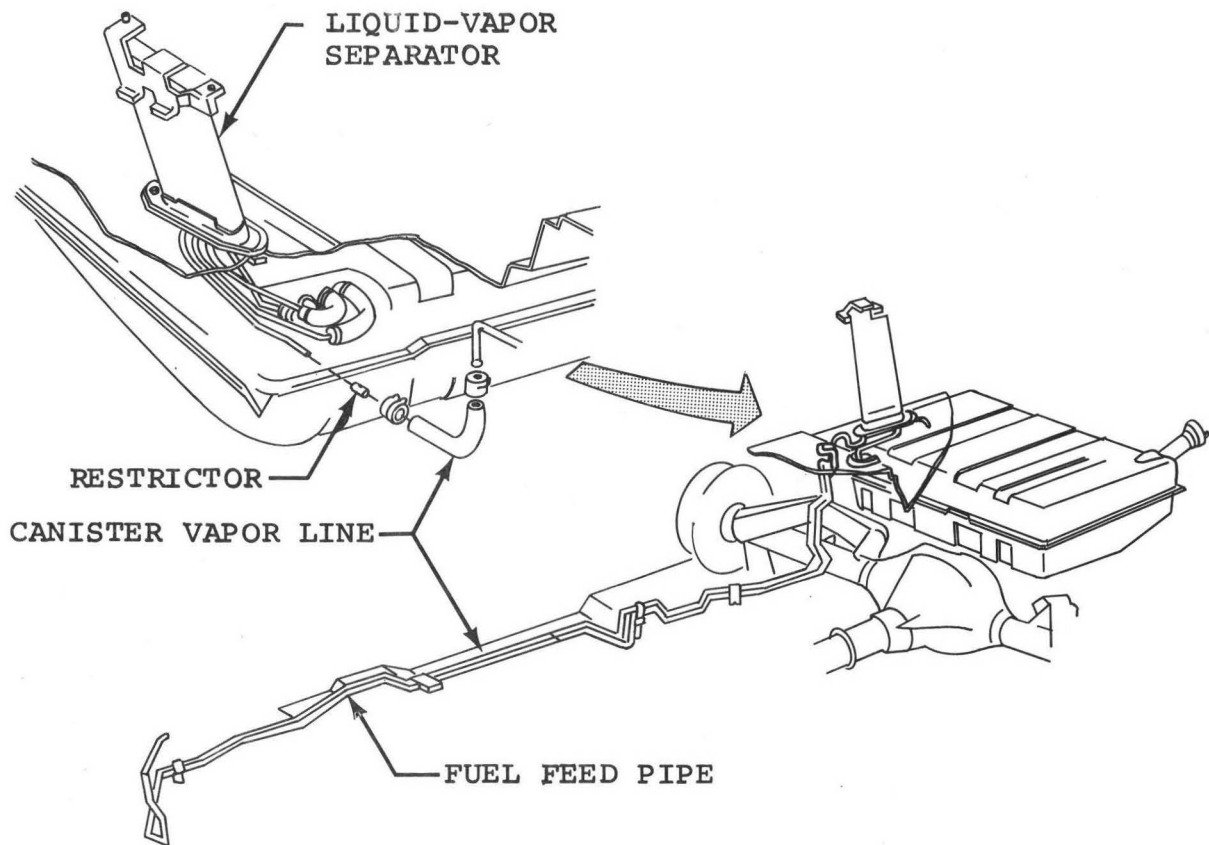


Figure 4-35. 1971 Vega Evaporative Control System.

The fuel tank, which incorporates a special internal fill limiter and vapor vents, is slung under the vehicle floor with two metal straps and is located at the extreme rear of the car on the right side. The filler cap containing the pressure-vacuum relief valve is the double-locking type found on the other 1971 Chevrolets.

The liquid-vapor separator is located in the right rear quarter panel and is shielded from the trunk contents by a plastic panel which forms the inside right wall of the trunk. The fuel tank vapor hoses all exit the tank at the upper right corner. Short lengths of hose from the vent connections are doubled back and fastened to metal lines which run into the separator assembly, as shown in Figure 4-35.

The vapor line between the separator and the carbon canister consists of a metal line leaving the separator, a short length of hose containing a flow restrictor to prevent liquid flow through the vapor line, and a metal line routed up the right side of the vehicle to the engine compartment. The line is then routed across the engine compartment firewall and up the left fender skirt to the carbon canister, which is mounted in the left forward part of the engine compartment.

The carbon canister used in the Vega is very similar to the staged purge canister used in the other Chevrolet systems. However, the Vega canister contains an extra inlet, shown in Figure 4-36, which leads directly into the carbon portion of the canister. This inlet is provided for a hose leading from the pressure relief valve which externally vents the carburetor float bowl under extreme conditions.

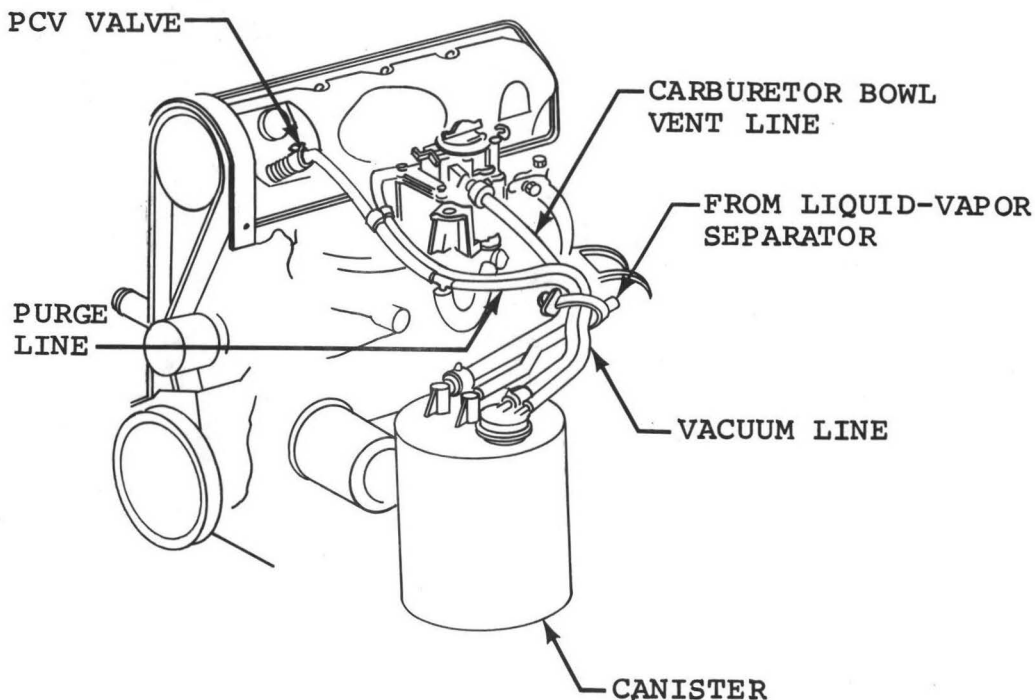


Figure 4-36. Vega Evaporative Control System Canister and Hoses.

A departure from the regular Chevrolet fuel system is also found in the Vega fuel feed system. The Vega incorporates an electric fuel pump located in the fuel tank. The fuel pump is energized when the ignition key is in the start position. The pump then receives current through the oil pressure safety switch as long as there is approximately 2 pounds of engine oil pressure. If the oil pressure drops below this level, contact is broken at the pressure switch and the pump is deactivated.

4.3.3 1971 Pickup Trucks. The evaporative emission control system used in the 1971 Chevrolet 1/2-ton pickup truck is shown in Figures 4-37 and 4-38. The metal fuel tank is mounted behind the seat in the cab and is bolted to the rear of the cab and to the floor panel. The metal filler neck, which is welded to the left top corner of the tank, extends through the left side of the cab approximately 1-1/2 inches. The filler cap is equipped with a pressure-vacuum relief valve. An extended filler neck within the fuel tank limits the fuel fill.

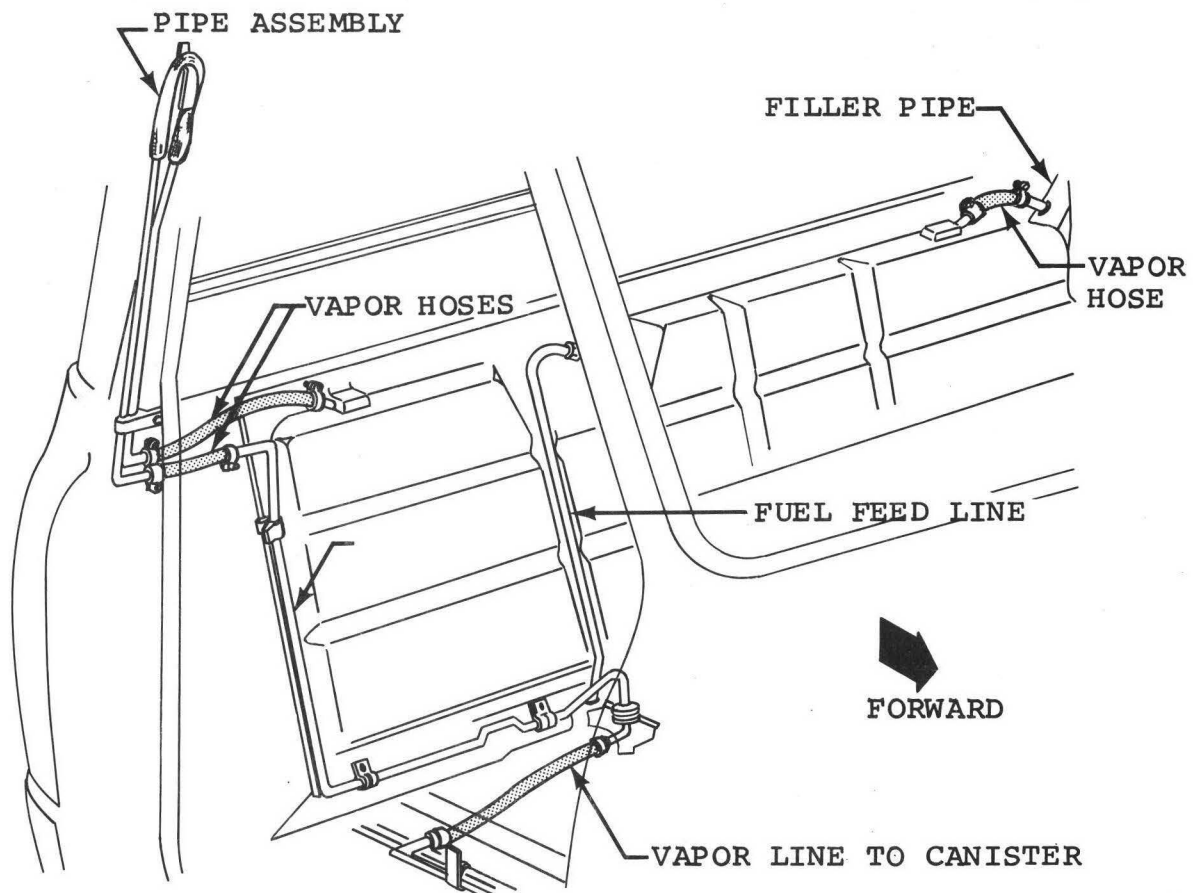


Figure 4-37. 1971 Chevrolet One-Half-Ton Pickup Truck Evaporative Control System.

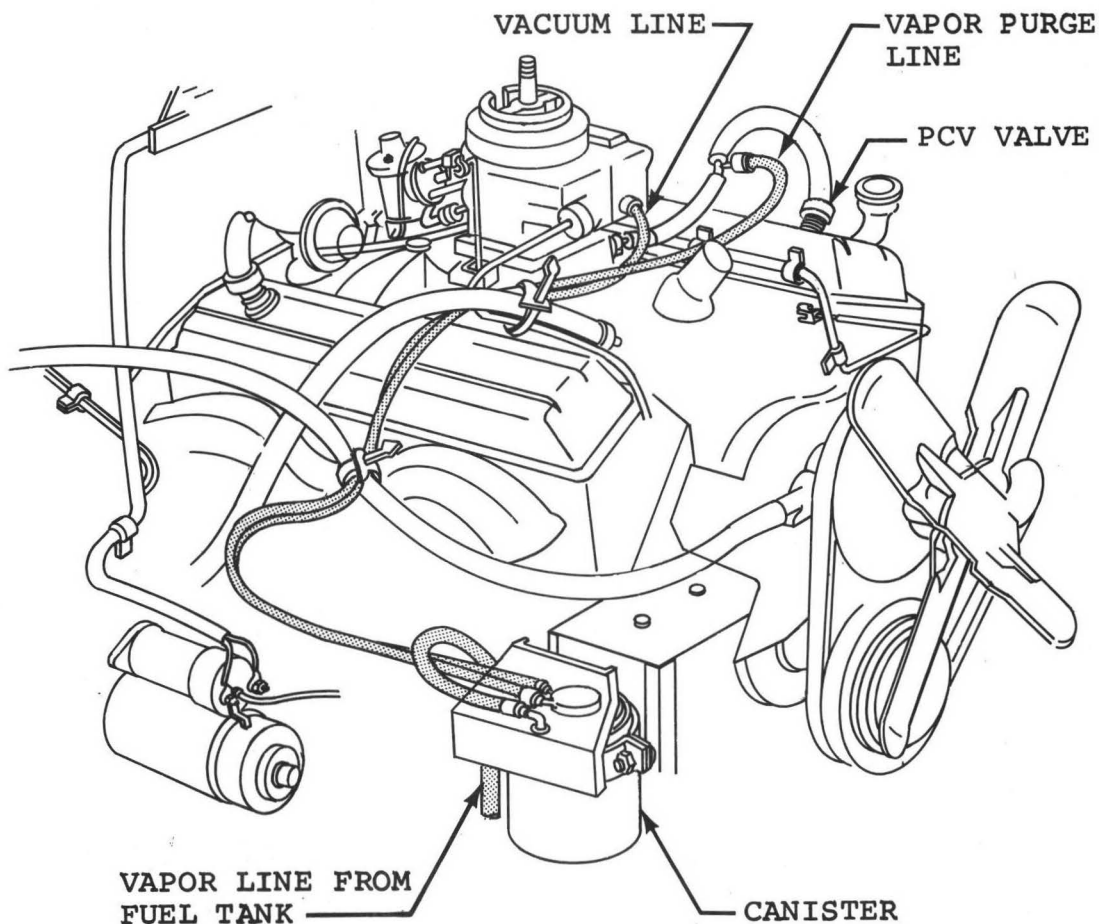


Figure 4-38. 1971 Chevrolet Pickup Truck Evaporative Control System Canister and Hoses.

The liquid-vapor separator consists of a vertical looped pipe located in the right side structure of the cab behind the door, as shown in Figure 4-37. The separator is completely enclosed except at the bottom where the vapor hose from the right top corner of the tank is joined. This vapor hose and the filler neck vapor vent at the left top of the tank are located at the outer corners of the tank and are completely exposed.

The vapor line from the separator to the canister is routed down the right side of the tank to the floor, inward approximately a foot, through the floor, and back to the right side under the floor. It is then routed forward to the canister which is located in the extreme right front of the engine compartment. The canister is bolted to the right front fender skirt and is located approximately 1 inch away from the battery.

The canister is the General Motors' canister used in the staged purge system and contains the purge valve. The purge line from the canister is connected with a tee into the PCV hose, while the vacuum signal line is connected to a port in the carburetor (see Figure 4-38).

4.4 CHRYSLER CORPORATION

4.4.1 1970 Passenger Cars. The 1970 Chrysler evaporative emission control system is shown schematically in Figure 4-39. The sealed fuel tank contains an internal thermal expansion tank which allows for possible fuel expansion and also serves as a fill limiter. Pressure and vacuum relief provisions are provided by the filler cap which will release vapor under 1/2 to 1 psi pressure or admit air under 1/4 to 1/2 psi vacuum.

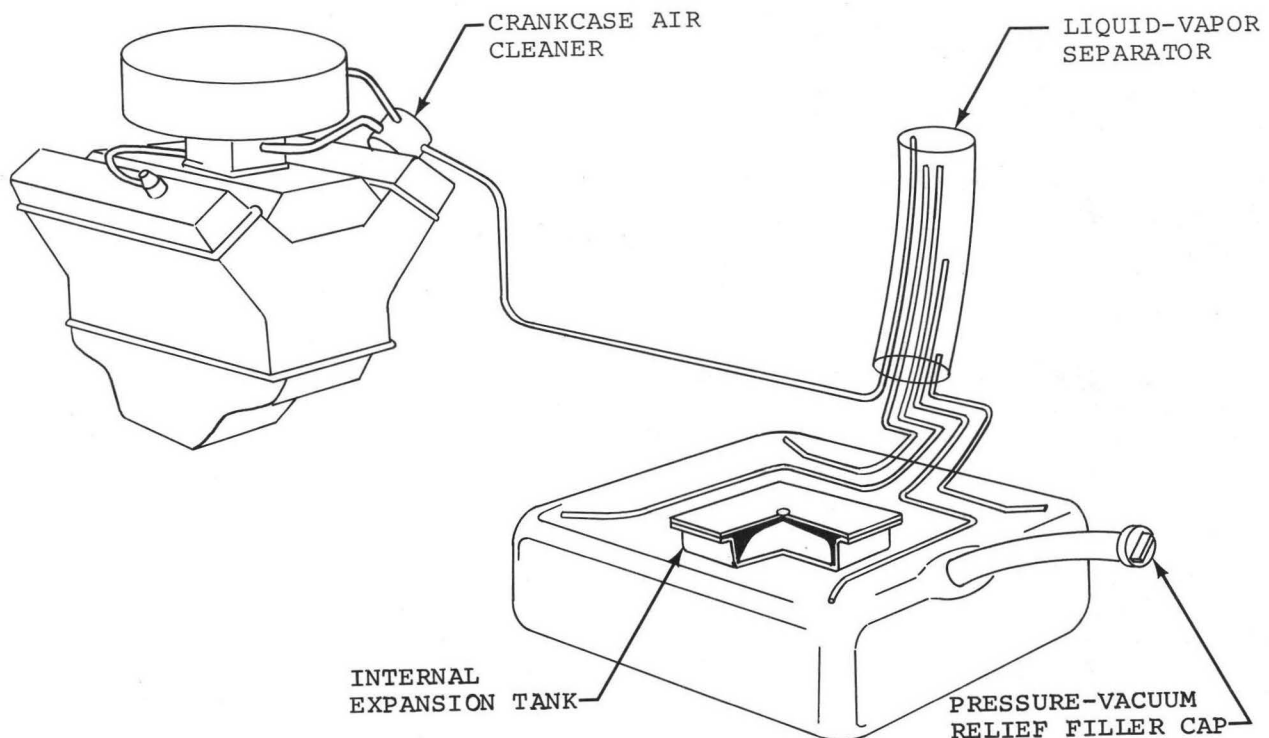


Figure 4-39. 1970 Chrysler Evaporative Control System.

Vapors from the fuel tank are conducted through four internal tank vents connected to a liquid-vapor separator outside the tank by rubber hoses. The liquid-vapor separator is a standpipe assembly consisting of a length of 2-inch steel tubing which internally holds the four vent lines from the tank and a vent line which leads to the crankcase inlet air cleaner. The internal

lines are of different heights to provide for tank venting regardless of vehicle attitude. The short vent line provides a drain to the tank for any liquid fuel which may get into the separator during normal operations. The vent to the crankcase is at the highest point in the separator and has a small (1/16-inch) orifice at the top to minimize any liquid fuel transfer to the crankcase. The liquid-vapor separator is mounted inside the trunk of the vehicle just behind the wheelhouse.

The fuel vapors from the separator are routed to the crankcase air cleaner for storage in the crankcase itself. With the engine running, the fuel vapors are purged from the crankcase along with the normal crankcase vapor and are drawn into the engine through the PCV valve for combustion.

Fuel vapors from the carburetor bowl are also routed to the crankcase for storage. The vapors are vented from the carburetor through a bowl vent valve which is closed during acceleration, but opens during idle operations and when the engine is off. On 8-cylinder engines the vapors flow through a hose connection from the bowl vent valve to the crankcase inlet air cleaner, while on 6-cylinder engines the vapors are routed to the crankcase through the base of the fuel pump.

The installation of the Chrysler evaporative control system is typified in the 1970 Dodge sedan. The Dodge fuel tank is located at the extreme rear of the body and is slung under the trunk compartment floor by means of two metal straps. The filler tube is located in the rear of the fuel tank.

The fuel tank liquid-vapor separator assembly is shown in Figure 4-40. The vapor vent hoses between the tank and the separator are routed under the trunk floor and protected from underneath by a lightweight shield. The separator is easily visible in the trunk compartment but is located at the extreme right side of the trunk against the wheelhouse and is thus out of the way.

The vapor line from the separator to the engine compartment consists of a metal line, joined to the separator by a short piece of hose, which is routed up the right side of the vehicle underneath the car. After the line reaches the engine compartment, it is joined to an approximately 12-inch length of rubber hose which attaches to the crankcase air cleaner outlet. The engine compartment routing of the vapor hoses shown in Figure 4-41 is typical of that used with Chrysler V-8 engines.

4.4.2 1971 Passenger Cars. The 1971 Chrysler evaporative emission control systems are essentially unchanged from those used in the 1970 models. The only difference is a minor variation in some of the vapor separator shapes and locations, although the standpipe type of separator is still used. One of these variations, which is shown in Figure 4-42, occurs in the

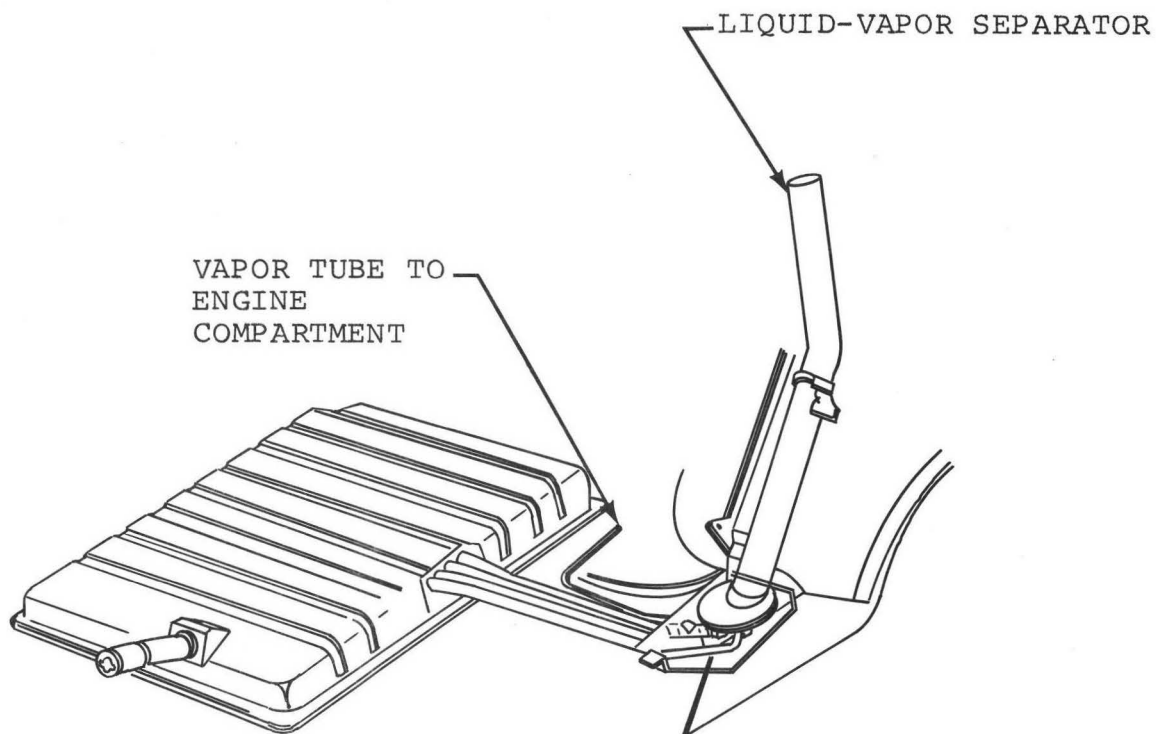


Figure 4-40. 1970 Dodge Evaporative Control System.

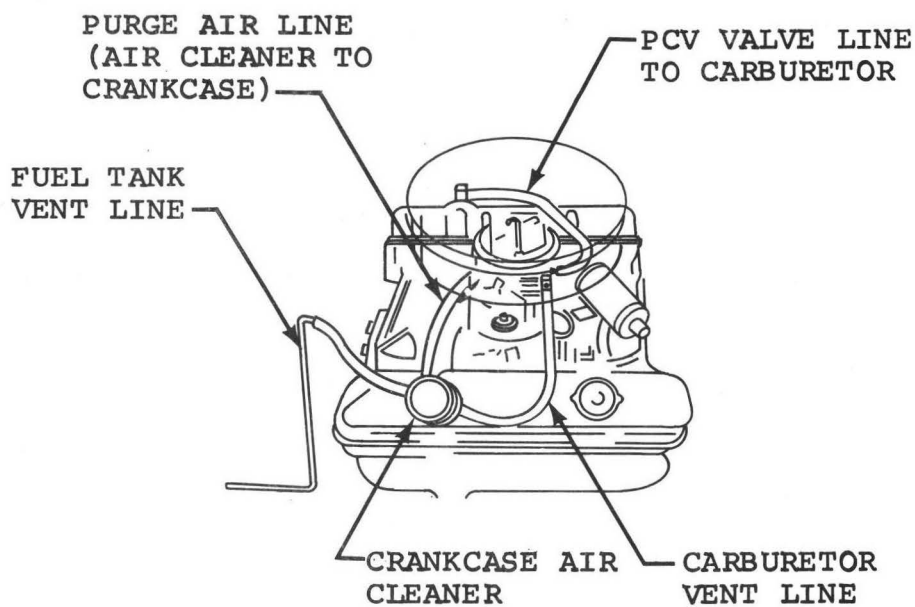


Figure 4-41. Chrysler Evaporative Control Hose Routing in Engine Compartment.

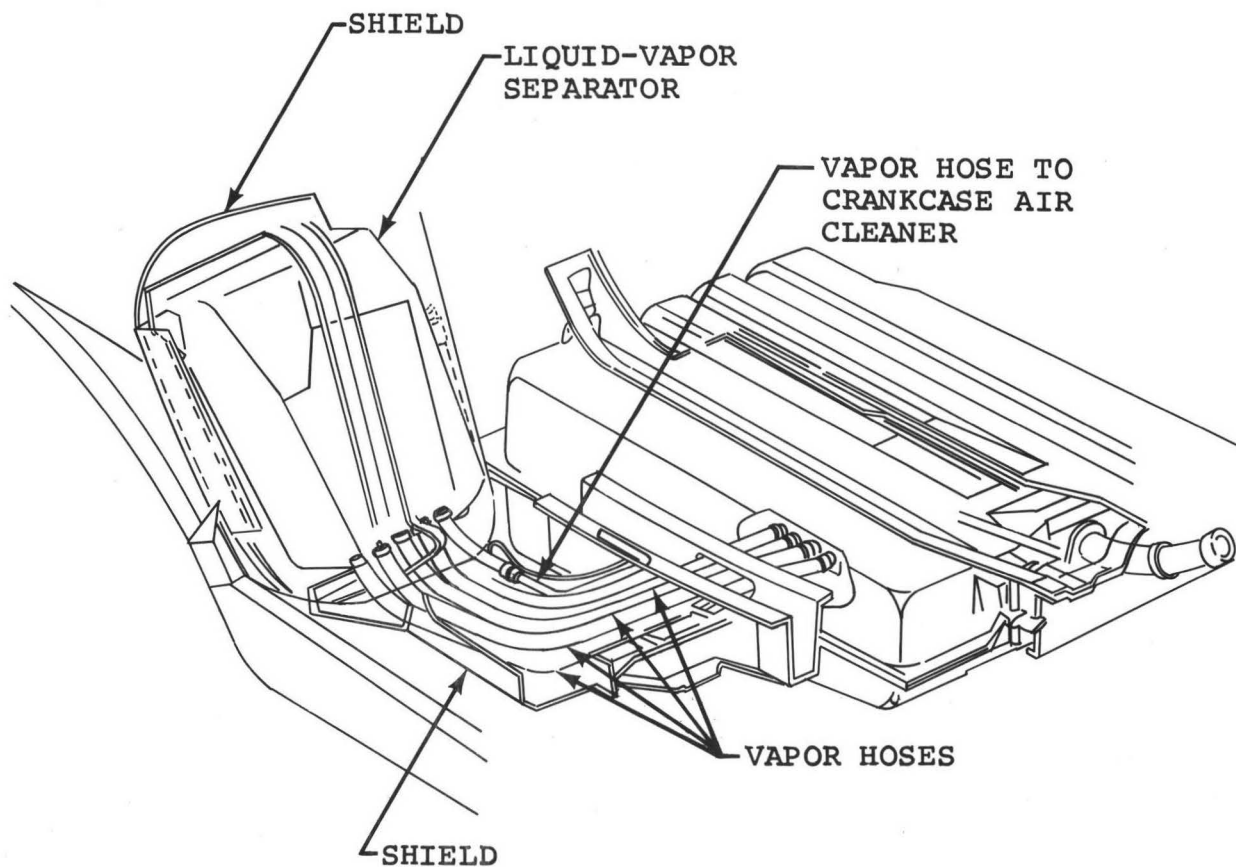


Figure 4-42. 1971 Satellite Fuel Tank and Liquid-Vapor Separator Assembly.

1971 Plymouth Satellite. The standpipe assembly is located in the left rear wheel housing rather than in the trunk. The fuel tank vapor vent lines to the separator exit the left side of the tank and are routed through the left side rail to the separator. This places the hoses underneath the trunk floor so that no components of the system are located in the trunk compartment. Both the hoses and the separator are protected from damage underneath by lightweight shields.

4.4.3 1971 Plymouth Cricket. The evaporative emission control system of the Plymouth Cricket, which is manufactured in England, is similar in some ways to the evaporative control system found in the standard Chrysler passenger cars but does vary in certain other aspects. The similarities are evident in the fuel tank and liquid-vapor separator, but the pressure-vacuum relief provisions of the Cricket differ from those of the Chrysler. The Cricket also uses a carbon canister to store the vapors rather than storing them in the crankcase.

The Cricket fuel and evaporative emission control systems are shown in Figure 4-43. The fuel tank is located at the rear of the vehicle under the right side of the trunk floor and is bolted to the vehicle body. Fuel fill is limited by an inner chamber within the fuel tank. Internal vapor lines lead from the four corners of the tank to a metal standpipe liquid-vapor separator which is located forward of the fuel tank in the trunk compartment. The vapor lines from the tank to the standpipe run underneath the trunk floor. The vapor line leading forward to the engine compartment contains a small diameter (.060 inch) orifice at its upper end to prevent liquid fuel traveling through the separator rather than draining back to the fuel tank through one of the tank vent tubes.

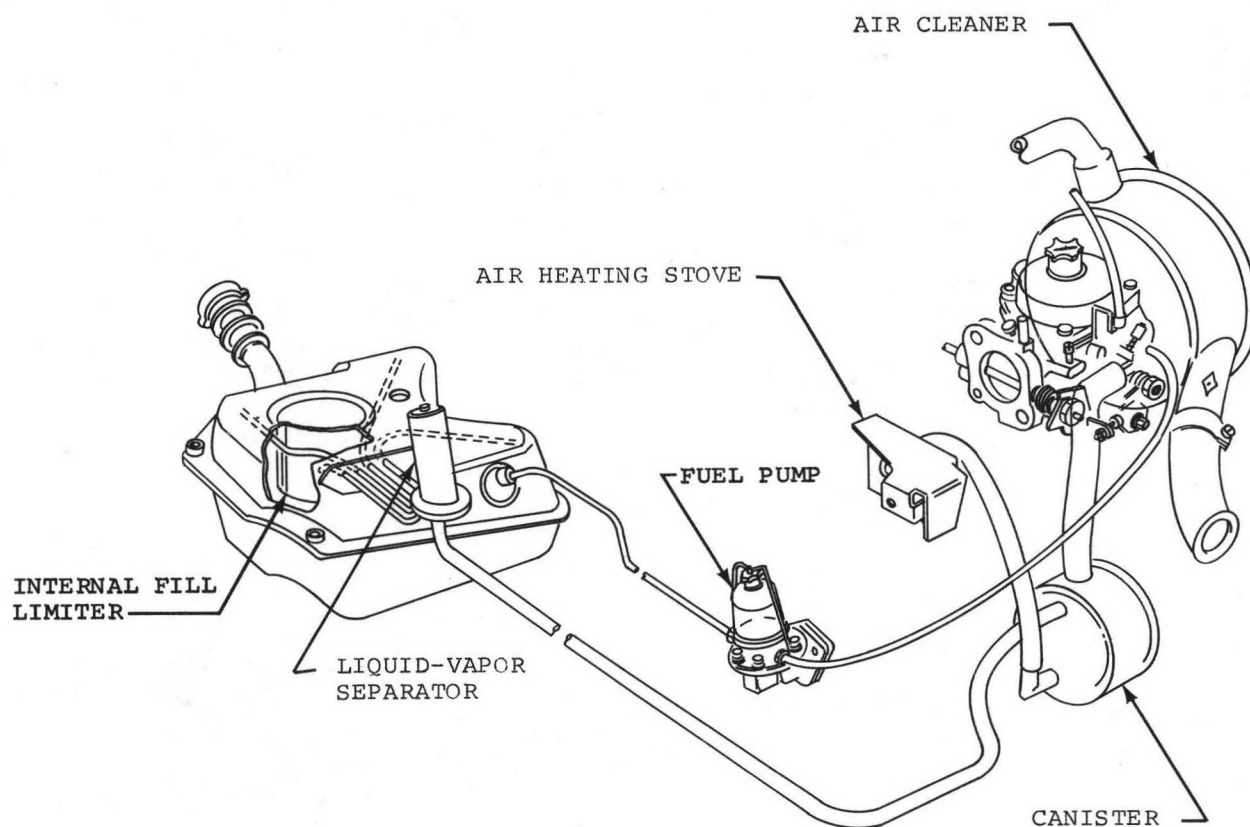


Figure 4-43. 1971 Cricket Evaporative Control System.

The fuel vapors are conducted from the separator through a plastic line running underneath the car to the carbon canister which is mounted on the left frame rail beside the engine. When the engine is started, air is drawn through a hot air stove near the exhaust manifold. The heated air is then drawn through the canister, purging the vapors through a hose to the air cleaner

mounted vertically above the canister. Service procedures for the Cricket call for the canister to be replaced at 5-year or 50,000-mile intervals, whichever come first.

Pressure-vacuum relief must come through the system as the filler cap is completely sealed. Air enters the air cleaner and travels back through the metal canister and the separator to the fuel tank to fill the space above the fuel while the fuel is being consumed.

One other significant difference between the Cricket and the standard Chrysler sedan is the design of the fuel pump. The Cricket fuel pump, which is mounted on the right side of the engine, includes a glass cover bowl. Fuel drawn from the tank enters the glass bowl from the front intake, passes through a filter and inlet valve, and then enters the pump chamber.

4.4.4 1971 Dodge Colt. The evaporative emission control system of the Dodge Colt, which is manufactured in Japan, is completely different from that found in the standard Chrysler passenger cars. The Colt system is very similar to those in other Japanese automobiles (Toyota and Datsun) in that a separate metal expansion tank is provided and a purge valve is used to control the flow of fuel vapors to the engine.

The evaporative emission control system of the Dodge Colt is shown in Figure 4-44. The fuel tank is installed under the luggage compartment floor and filled through a sealed filler cap located in the left rear quarter panel. A long flexible hose forms the filler neck.

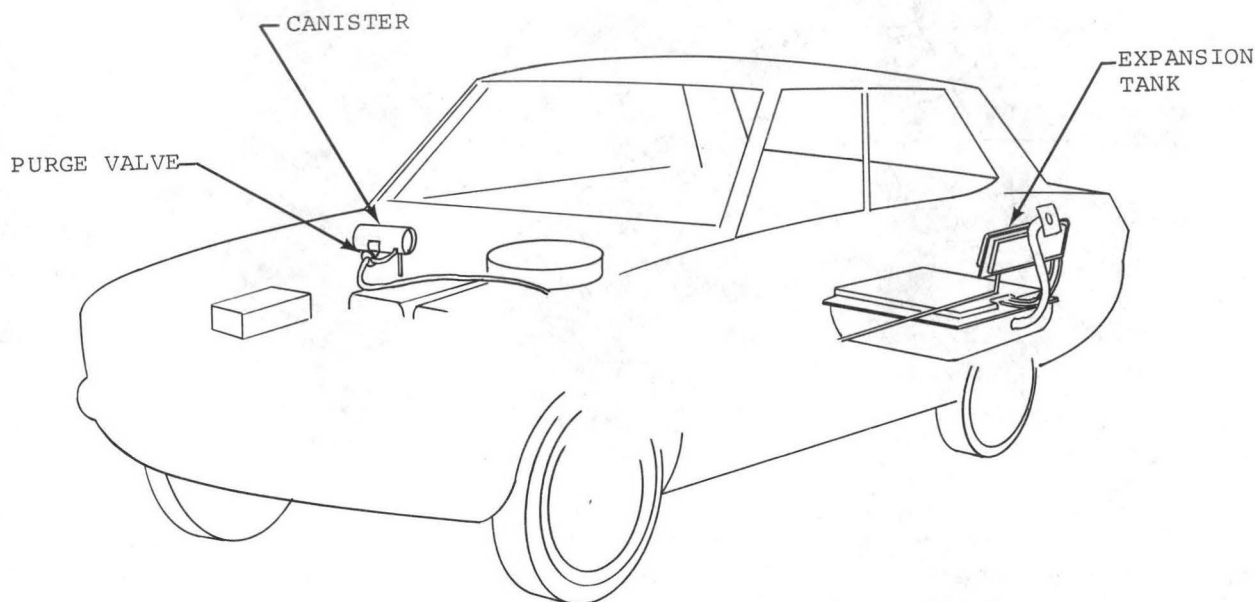


Figure 4-44. 1971 Dodge Colt Evaporative Control System.

A metal sub-tank is used both for fuel expansion space and as a liquid-vapor separator. The sub-tank is located inside the trunk in the left fender well approximately 10 inches higher than the trunk floor. Flexible plastic vapor lines run from the top left side of the fuel tank through the trunk floor and upward through the left fender well area to the sub-tank. These vapor lines and the sub-tank are completely exposed in the trunk area with no shielding between the trunk compartment and the tank or vapor lines.

Vapors are routed from the sub-tank to the engine compartment through a metal line running under the left side of the car to the firewall and then to the right side of the engine compartment. A short piece of flexible hose connects the vapor line to the canister which is mounted at the top right side of the engine compartment on the firewall. The charcoal filled canister contains a paper filter type air cleaner in the purge air inlet side and a paper filter for charcoal removal on the vapor outlet side. During engine operation, a vacuum-actuated purge valve mounted on the canister is opened, drawing air in through the end of the canister and sweeping the vapors through the valve into a flexible hose routed over the top of the engine and into the intake manifold on the right side of the engine. When the engine is shut off, the purge valve is closed. Vacuum relief must come through the canister purge air inlet and back through the system to the fuel tank.

Maintenance instructions call for replacement of the canister filter paper and air cleaner element every year or every 12,000 miles, with replacement of the charcoal every 50,000 miles.

4.5 AMERICAN MOTORS CORPORATION

4.5.1 1970 Passenger Cars. The American Motors evaporative emission control system consists of a sealed fuel tank, a filler cap containing a pressure-vacuum relief valve, vapor vent lines, and a liquid check valve located in the vent system. The vapors are stored in the crankcase.

The Rebel and Ambassador evaporative emission control system is shown in Figure 4-45. The fuel tank is suspended from the rear of the underbody by two steel straps. The fuel tank contains an integral expansion tank to provide a displacement area for fuel expansion. The two fuel tank vent lines are routed to a liquid check valve which incorporates a float and needle assembly. In the event that liquid fuel enters the check valve, the float will rise and force the needle upward to close the vent passage, thereby preventing liquid fuel flow through the valve. No liquid-vapor separator as such is used in this system.

After passing through the check valve, the vapors are routed through a metal line under the floor on the left side to the

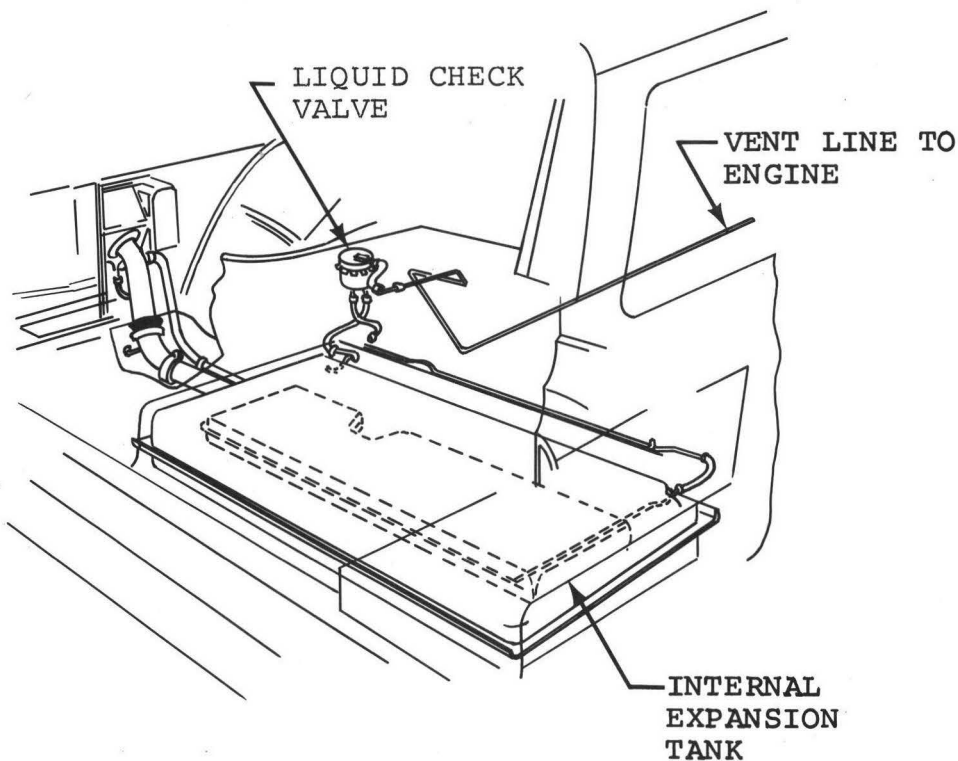


Figure 4-45. 1970 American Motors Evaporative Control System (Rebel and Ambassador).

cylinder head cover of the engine. On V-8 engines, the vent line is routed to the left cylinder head cover. The fuel vapors are stored in the crankcase and, when the engine is running, drawn into the PCV system and burned along with the normal fuel/air mixture.

Pressure-vacuum relief provisions are provided by a two-way relief valve in the filler cap. The valve is designed to open under a pressure of .50 to 1 psi, or .25 to .50 inches of vacuum within the tank. The filler is located in a recessed opening on the side of the left rear fender behind a hinged cover door. The filler tube is connected to the fuel tank inlet by a rubber hose secured with clamps. The metal filler tube and the plastic filler vent line are exposed in the left fender well of the trunk compartment.

This same basic system is used on all of the AMC passenger cars although some of the vehicles contain only a single tank vent line as shown in Figure 4-46.

4.5.2 1971 Passenger Cars. The AMC evaporative control system in the 1971 passenger cars is essentially the same as that found in the 1970 models. However, 1971 models equipped

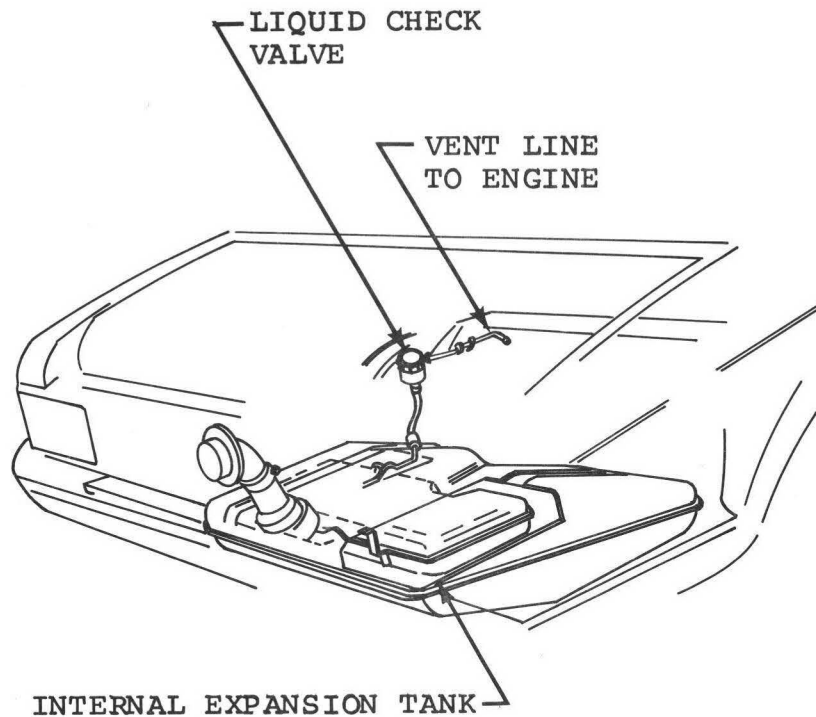


Figure 4-46. American Motors Single Vent Evaporative Control System.

with a V-8 engine and automatic transmission contain a carbon canister very similar to the staged purge canister used by General Motors. The purge line from the canister connects into the PCV system. The vent lines on all 6-cylinder engines and on V-8 engines with manual transmissions still connect to the valve cover (see Figure 4-47).

The Gremlin evaporative control system differs in two respects from the general AMC system. The Gremlin fuel tank was designed to provide an adequate air displacement area for fuel expansion and does not contain an internal expansion tank. In addition, the Gremlin system does not contain the liquid check valve. The rest of the Gremlin system is identical to that found in the other AMC passenger cars.

4.6 VOLKSWAGEN

4.6.1 1970 Passenger Cars. The evaporative emission control systems used in the 1970 Volkswagen passenger cars consist of a sealed fuel tank, a combination expansion chamber and liquid-vapor separator, and a charcoal canister.

The evaporative control systems in the two-door sedan (Beetle) and the Ghia are identical. The system is shown in

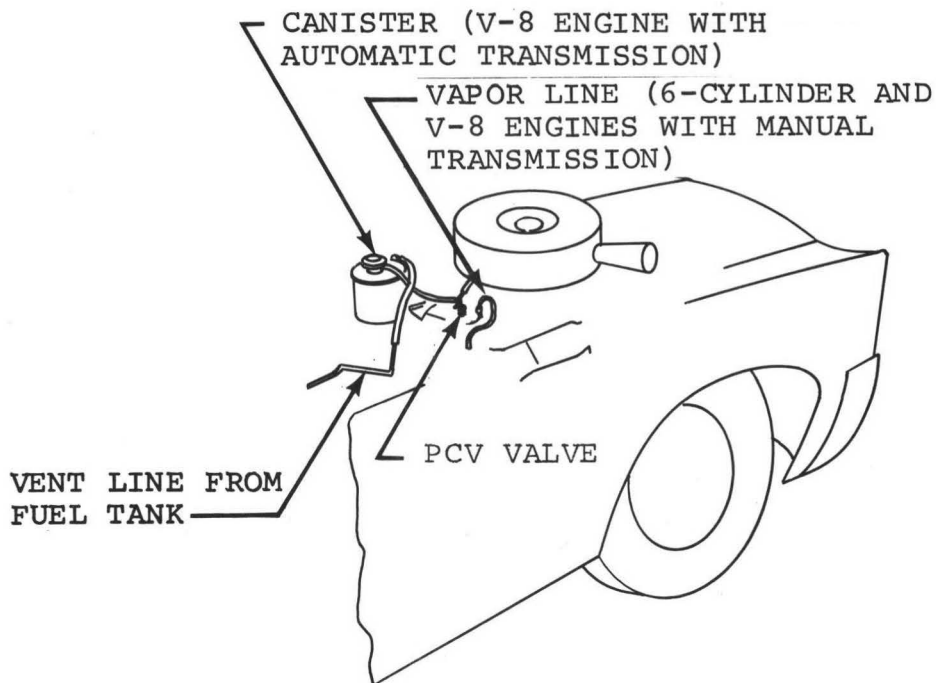


Figure 4-47. 1971 American Motors Evaporative Control System Canister and Hoses.

Figure 4-48. The fuel tank is located in the forward part of the luggage compartment just behind the spare tire. The flat top of the tank serves as the luggage compartment floor and is protected by a stiff rubberized mat. The sealed filler cap is located in the right side of the vehicle near the rear end of the luggage compartment. The filler neck consists of short pieces of rubber-lined fabric hose at the filler cap and fuel tank connections and an interconnecting plastic filler pipe. The fuel tank is held in place by metal clips that fit over the flange of the fuel tank. The clips are bolted to the luggage compartment floor.

The fuel tank is vented from the right rear corner by means of a filler vent and a short vent line which connects the filler vent to the breather line. The breather line, which vents the left front corner of the tank, is routed across the rear luggage compartment wall into the right fender and forward to the expansion chamber. The breather line and vent lines are all made from a rubberized fabric material.

The metal expansion chamber is located on the right side of the luggage compartment. It is well protected by a metal cover. The cover and chamber are held on the right hand panel by a metal strap welded to the body structure.

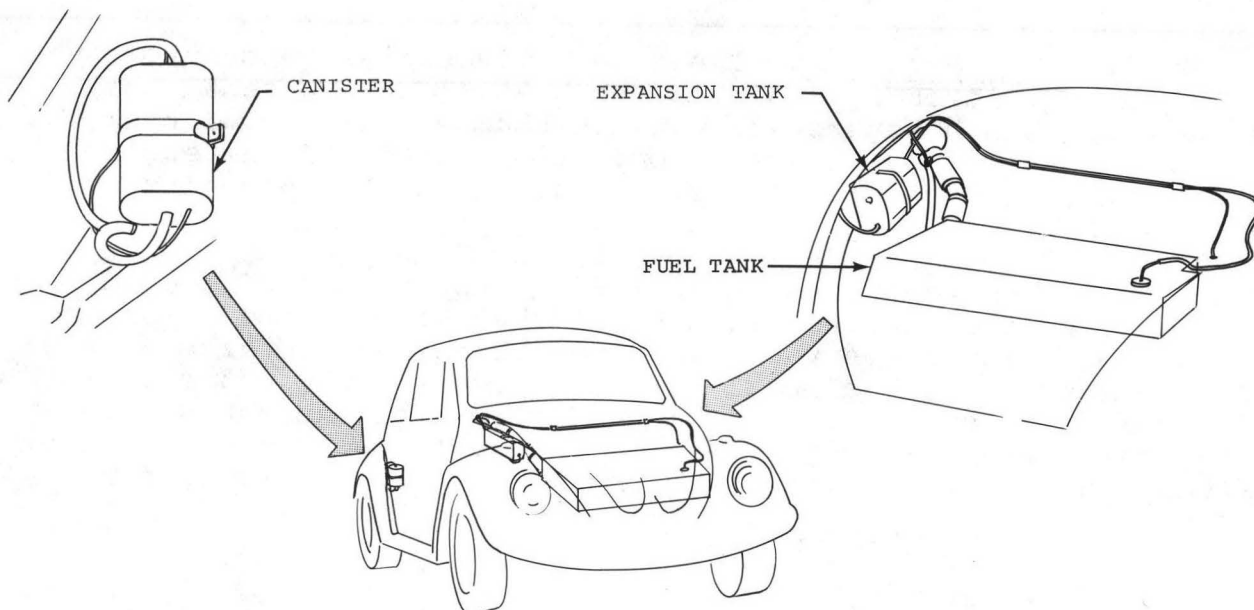


Figure 4-48. 1970 Volkswagen Sedan Evaporative Control System.

The vapor line leading to the canister exits the rear end of the expansion chamber and is routed back and across the luggage compartment wall to the left side. It passes through the luggage compartment floor near the left fender well and is joined to a steel vapor line routed under the car to the right rear fender well. Although the vapor lines are routed out of the way of the trunk contents, they are not shielded.

The charcoal canister is mounted in the right rear fender well. It is held in place by a metal strap welded to the in-board body panel of the fender well. The vapors from the expansion chamber enter the bottom of the canister through a fabric-covered rubber hose which connects to the vapor line under the car. Purging of the vapors from the canister is accomplished when the engine is running by air blown into the top of the canister from the cooling fan. The vapors are drawn from the bottom of the canister through a rubber lined fabric hose to the oil bath air cleaner and from there into the carburetor.

The same system is used in the Squareback and Fastback. However, the component locations differ from those found in the Beetle and the Ghia. The expansion chambers in the Squareback and Fastback are located under the left front fenders while the charcoal canisters are located in the left rear part of the engine compartments.

No separate pressure-vacuum relief component is provided in the system. Vacuum relief must come through the system by means of the charcoal canister.

4.6.2 1970 Microbus. The evaporative emission control system in the VW microbus is similar to that of the VW sedan but does not contain a separate expansion chamber. The fuel tank, which is located in a separate compartment ahead of the engine compartment, is provided with additional internal space for expansion.

A fuel tank vent line runs from the upper part of the fuel tank to an adapter located in the wall between the fuel tank and engine compartments. A vapor line in the engine compartment runs from the adapter to the metal carbon canister. The canister is located in the top forward right-hand corner of the engine compartment, as shown in Figure 4-49. The fuel vapor is purged from the canister by air entering the canister from the blower fan.

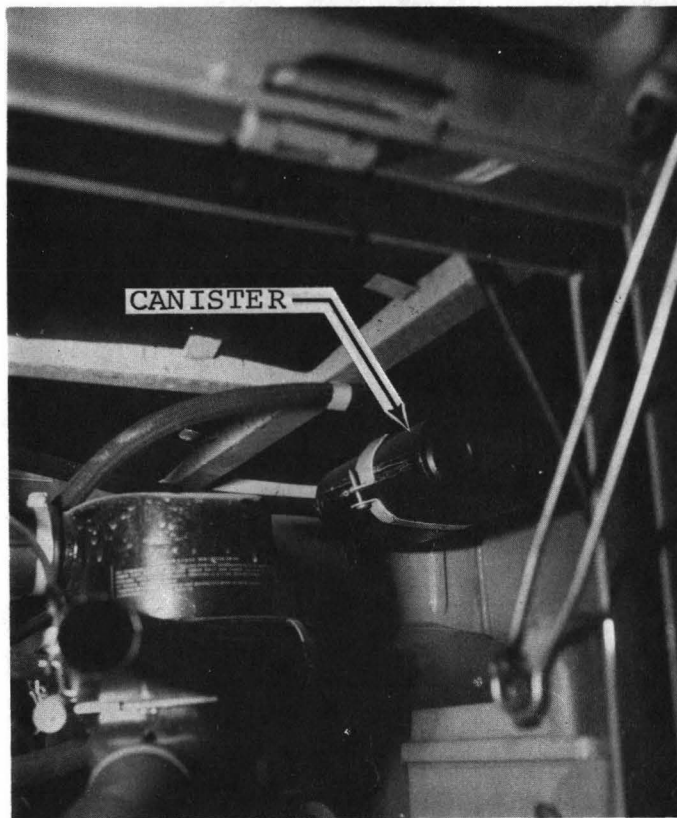


Figure 4-49. Carbon Canister in 1970 VW Microbus.

The purged vapors are routed through a line about 18 inches long directly from the canister to the air cleaner. The vapor lines are made from a fabric-covered rubber hose similar to that

used in the sedans. All of the hose connections consist of a tight fit only; no clamps are used.

The system contains an unvented filler cap, and vacuum relief must come through the system from the air cleaner and canister back to the fuel tank.

4.6.3 1971 Passenger Cars. The evaporative emission control system used in the 1971 VW Beetle is identical to that used in the 1970 model. The system used in the Super Beetle is similar but does not incorporate a separate expansion tank. Expansion space is provided within the fuel tank itself.

The fuel tank in the Super Beetle is located in the rear of the luggage compartment (shown in Figure 4-50) rather than in the front. The fuel tank is vented from both rear corners. The right vent line is routed to the filler pipe vent. The hoses from the two left rear vent outlets are routed across the back of the luggage compartment and joined with a tee to the vent line coming from the filler vent. The vent line is then routed back across the luggage compartment (at the top rear) to the left side and through the luggage compartment floor. This hose then joins a metal vapor line leading to the canister in the right rear fender well. The canister is identical to that used in the VW Beetle and purging is accomplished in an identical manner. The fuel tank and most of the lines in the luggage compartment are protected by a fiberboard cover.

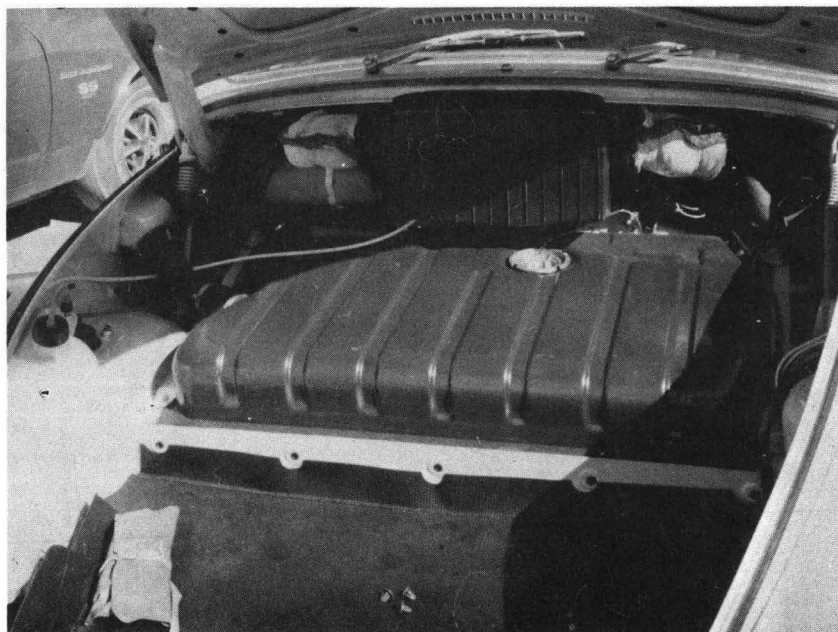


Figure 4-50. 1971 VW Super Beetle Fuel Tank.

The filler cap in the Super Beetle is unique in that it contains synthetic polymer threads approximately 1-1/2 inches long which screw into the filler neck. A mechanical stop is provided to prevent damage to the threads from over-torqueing.

No separate pressure-vacuum relief provisions are provided in the system. Vacuum relief must come through the air cleaner and canister as in the other Volkswagen systems.

4.7 TOYOTA MOTOR COMPANY

4.7.1 1970 Passenger Cars. The Toyota evaporative emission control system consists of a sealed fuel tank, a metal thermal expansion tank, a metal vapor storage tank, and a purge control valve.

The Toyota Corolla evaporative control system is shown in Figure 4-51. The fuel tank is located over the rear axle just behind the rear seat and is shielded from the trunk compartment by a fiberboard panel. The thermal expansion and vapor storage tanks are located above the fuel tank and are bolted to the underside of the rear package shelf. The arrangement of these components in relation to each other and to the vehicle structure is shown in Figure 4-52.

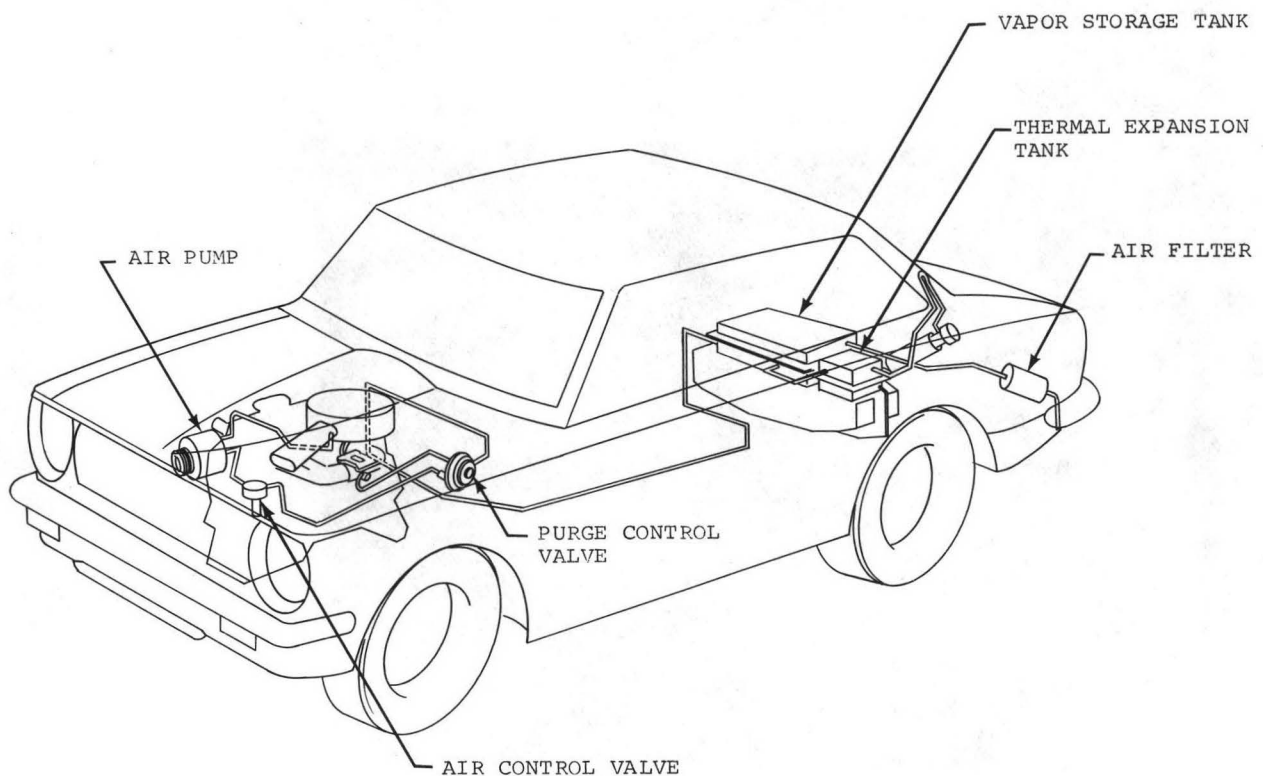


Figure 4-51. 1970 Toyota Corolla Evaporative Control System.

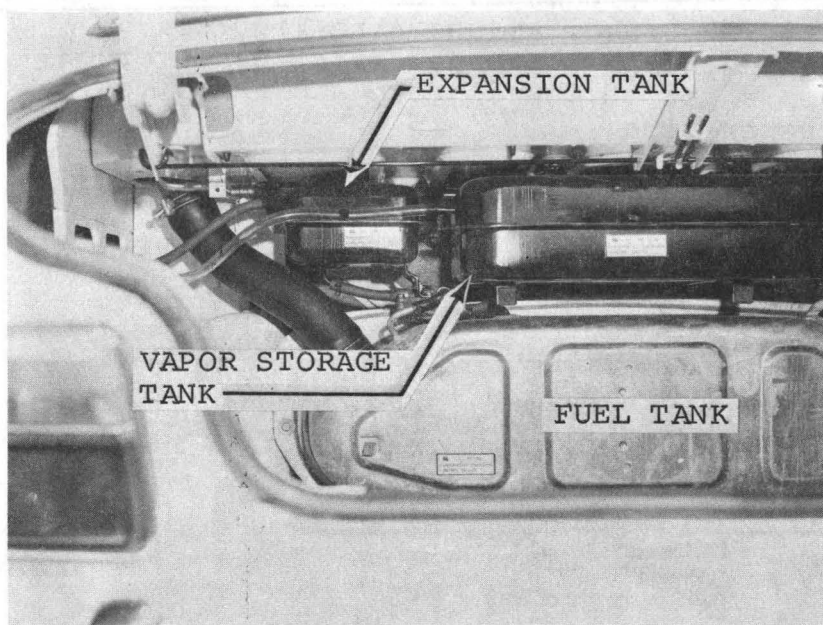


Figure 4-52. 1970 Toyota Corolla Fuel, Expansion, and Vapor Storage Tanks.

Some of the interconnecting vapor lines are made from rubber while others are made from a flexible plastic. A long vent line from the filler neck to the thermal expansion tank consists of a looped metal tube located in the left rear roof pillar between the sheet metal and the head lining. The metal tube is connected at both ends with short pieces of rubber hose.

An air filter is located in the left rear fender well of the trunk and is attached to the vapor storage tank with a flexible plastic hose. A short piece of rubber hose leads from the air filter through a hole in the underfloor structure to the outside.

The vapor line from the storage tank is routed down the right side of the tank and through the floor to a metal line which runs forward under the center of the car to a purge control valve in the engine compartment. The purge control valve is closed when the engine is not running. When the engine is running, the air pump provides air through the air control valve to open the purge control valve. This allows the engine vacuum to draw air from the air filter located in the rear of the car through the vapor storage tank to purge the vapors up through the valve and into the intake manifold. Pressure-vacuum relief provisions are provided by the air filter located in the rear of the car. Maintenance procedures call for the air filter to be cleaned every 12,000 miles.

The Toyota Corolla contains an electric fuel pump mounted in the right side of the trunk just above the fuel tank and adjacent to the vapor storage case, as shown in Figure 4-53. The fuel line exits the tank from the upper right hand corner. From the pump, the line is routed down underneath the floor in close proximity to the vapor line.

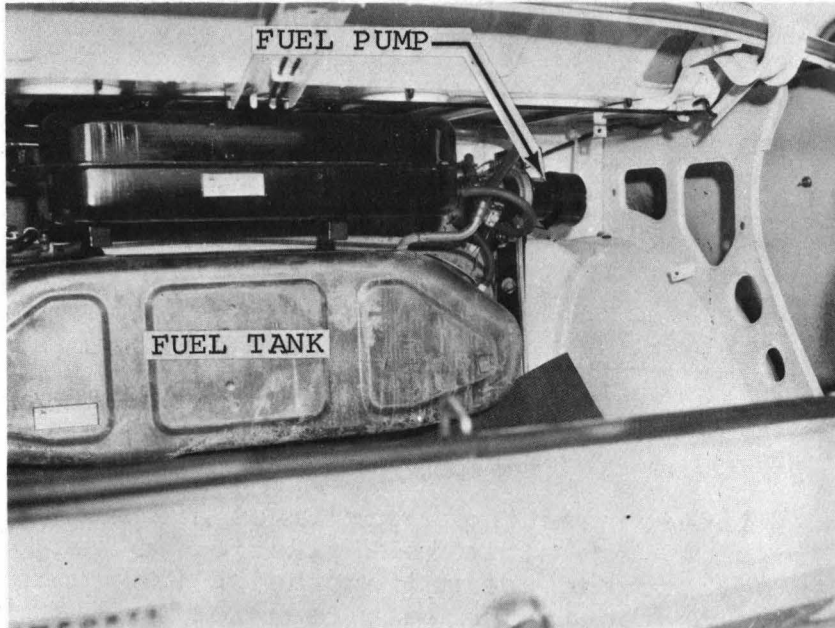


Figure 4-53. 1970 Toyota Corolla Fuel Tank and Fuel Pump.

The same basic system is used in the remaining Toyota sedans but the location of the components varies. The fuel tank is located underneath the trunk floor in the Corolla, the Corolla Mark II, and the Crown sedans. The Mark II uses a vacuum purge valve rather than the air-actuated valve found in the other sedans. The largest difference in component location is found in the Crown sedan which contains two vapor storage cases, one located in each of the front fenders as shown in Figure 4-54.

4.7.2 1971 Passenger Cars. The 1971 Toyota evaporative emission control system is essentially the same as that used in 1970, although several changes in component location have been made.

The only change in the Toyota Corolla system has been the relocation of the carburetor and intake manifold to the right

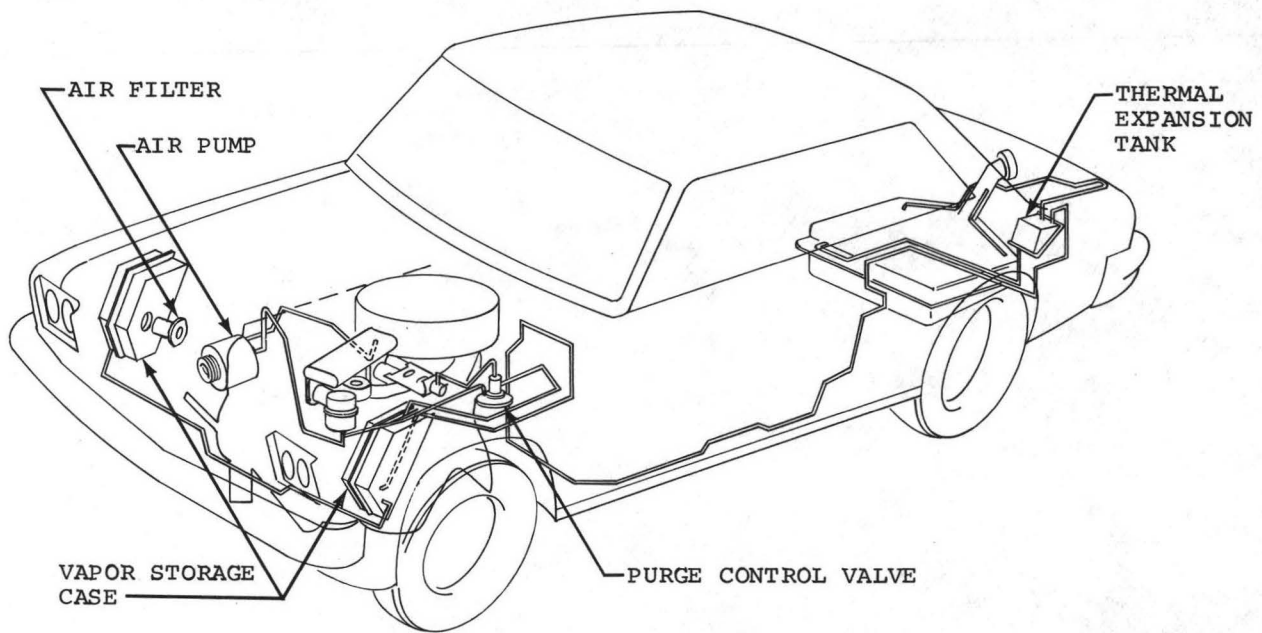


Figure 4-54. 1970 Toyota Crown Evaporative Control System.

side of the engine. The purge control valve is still mounted in the left side of the engine compartment with the purge line from the valve to the intake manifold routed over the engine.

The 1971 Toyota Crown now contains only one vapor storage tank rather than the two found in the 1970 models. The 1971 storage tank is mounted in the extreme front of the engine compartment in the left fender well area. The vapor storage tank in the Corona Mark II has also been moved into the engine compartment and it, too, is located in the front of the left fender well.

5. FUEL SYSTEM FIRE HAZARDS

5.1 GENERAL

The following sections present the fuel system fire hazards uncovered during the examination of new and crashed vehicles and the testing series conducted during this program. The analysis is concentrated on the fuel system with the exhaust and electrical system being mentioned only if obvious hazards exist.

An unsafe condition is assumed to exist in the presence of any liquid or vaporized fuel spillage, as potential ignition sources may be assumed to exist at all times. This is because ignition can occur not only from the electrical and exhaust systems of the vehicle but also from outside sources which cannot be controlled. These outside sources may consist of such items as a flame, for instance from a burning tire; a lighted cigarette; sparks from a broken power line; and, as a prime ignition source during collisions, static sparks generated from the scraping of metallic vehicle parts against the pavement.

The fuel system hazards uncovered during this program are grouped according to the conditions which cause the hazard, rather than by the particular fuel system involved. This manner of presentation facilitates uncovering the basic causes of the hazards and also prevents a great deal of repetition, as many hazards were found to be common among several vehicle fuel systems.

The conditions which may cause fuel system spillage have been segregated into normal operational conditions and crash conditions. This serves to roughly separate the hazards according to degree. In many instances leakage during operational conditions would not normally occur near ignition sources, and the main consequences of the spillage would be the defeat of the evaporative control system and less than optimum engine performance. Even should a fire start under operating conditions, the hazard to the occupants is usually not great as they can exit the vehicle before the fire becomes dangerous. The hazards under crash conditions, however, are much more severe for two reasons. Ignition sources, especially sparks from a damaged electrical system or static sparks, are likely to be present. In addition, occupant injury and/or vehicle deformation may severely limit the ability of the occupant to escape from a vehicle fire.

5.2 OPERATIONAL CONDITIONS

5.2.1 High Environmental Temperatures. Three factors must be considered in relation to temperature increases in the vehicle environment. These factors are the thermal expansion of the liquid fuel, the thermal expansion of the existing fuel vapor, and the additional fuel vapors generated.

Liquid gasoline expands at the rate of 0.0006 gallons per gallon per degree Fahrenheit temperature rise. A 30°F rise in fuel tank temperature can readily be envisioned after refueling due to differences between the underground storage temperature of the fuel and the environmental temperature. Such a temperature difference was, in fact, observed during the extreme temperature tests conducted during this program (Appendix C). A 30°F temperature rise would cause a 1.8 percent expansion of the liquid fuel or, in a 20-gallon fuel tank, an increase in volume of .36 gallons.

Two types of provisions for fuel expansion were noted in the study. Many of the smaller foreign imports use a separate expansion tank located above the fuel tank and connected to the fuel tank by means of hoses. Some of the imported vehicles and all of the American vehicles use an internal tank fill limiter consisting either of a small expansion tank within the fuel tank or a filler neck extending into the center of the fuel tank.

The expansion space provided in all of the vehicles seems more than adequate for any liquid expansion. The possibility does exist that some of the internal limiters could be filled by slow additions of fuel over a long time period, especially when the fill limiter consists only of a filler neck extending into the tank (see Figure 5-1). Automatic shutoff of the filler nozzle would occur as soon as the fuel level reached the top of the filler neck opening. However, as long as vapors could escape through the vent line, it would be possible to fill the tank completely by slow additions of fuel. This situation, of course, cannot exist if the vent line is closed by a relief valve, as in the 1970 Fords.

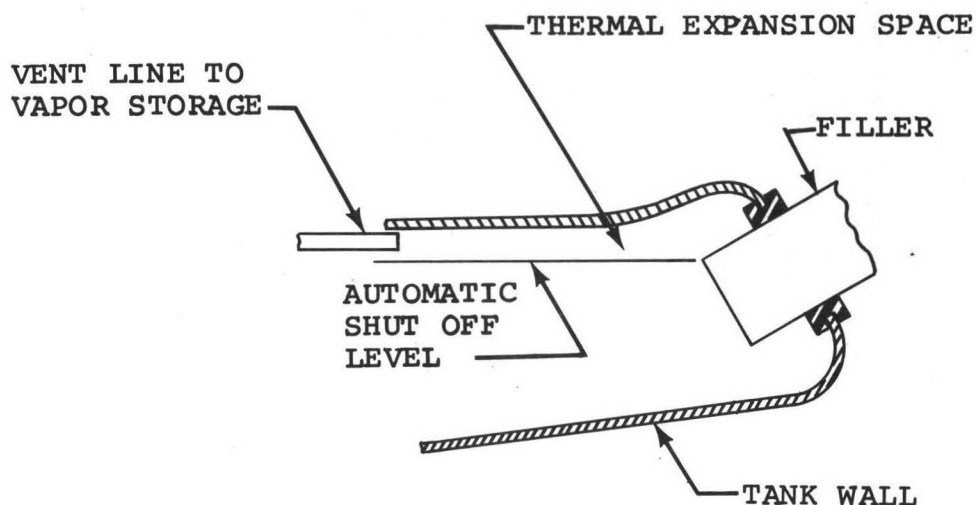


Figure 5-1. Extended Filler Neck Fill Limiter.

Internal expansion tanks containing top vents, as in the Chrysler system, could also be overfilled but the time required would be much longer than for the extended filler neck configuration. Chrysler found that their expansion tank, which contains 1/16-inch-diameter orifices in the top and bottom, would require approximately 45 minutes to fill (Ref 11). The separate expansion tanks, of course, could not be over-filled due to their location above the fuel tank. However, the simplicity of the internal fill limiter systems as opposed to the separate tanks and their associated hoses is desirable as the simpler systems contain less potential for component failures.

The vertically mounted tanks found in station wagons need no provision for fill limiting since the filler opening is located beneath the top of the fuel tank, thus preventing complete filling of the tank and assuring adequate liquid expansion space.

Calculating the vapor storage space necessary for temperature rises is more difficult than for liquid fuel expansion. The volume of already present vapor would increase approximately 6 percent for a 30°F temperature rise. However, additional vapor is also generated as the temperature increases.

Tests were conducted by Chrysler (Ref 11) to determine the quantity and composition of the vapors emitted from their fuel tank and liquid-vapor separator when they were subjected repeatedly to a diurnal procedure in which the temperature of the fuel was raised from 60°F in one hour to 85°F. (This soak procedure is the diurnal cycle required by the Department of Health, Education, and Welfare to qualify a vehicle under the evaporative emission standard for Control of Air Pollution from New Motor Vehicles, Title 45, Subtitle A, Part 85.) The vapors emitted during each diurnal cycle were collected, weighed, and analyzed. Sixteen grams of fuel vapor were recovered after the first soak cycle. These 16 grams of vapor would occupy approximately .2 cubic foot at 72°F.

Two types of vapor storage systems are in common use. One of these involves storing the vapor in a storage container, while the other system involves adsorbing the vapor on activated charcoal or carbon. Those manufacturers using container storage include Chrysler, American Motors, and Toyota. The measured volume available to store vapors in the Chrysler system is 1.6 cubic feet (Ref 11). It may be assumed that American Motors, which also stores their vapor in the crankcase as does Chrysler, would have approximately the same volume available. The Toyota Corolla vapor storage tank holds approximately .3 cubic foot which, together with approximately .1 cubic foot available in the expansion tank, gives the Corolla a total vapor storage capacity of approximately .4 cubic foot. Thus, the capacity of the Chrysler and American Motors system is more than ample for a fairly large temperature increase, while that of the Toyota, although more

limited, is still sufficient for a 25-degree temperature rise by a factor of 2.

All the rest of the vehicles analyzed during this program store the fuel vapors by adsorbing them on the surface of activated charcoal or carbon granules contained in a storage canister. The capacity of each canister will vary, depending on the total surface area of the adsorbing agent, the concentration or partial pressure of the fuel vapor, and the temperature at which adsorption occurs. The capacity will also depend on the particular blend of gasoline being used and its volatility. Since the capacity of the various carbon canisters could not be determined except by extensive laboratory testing which was beyond the scope of this program, it must be assumed that the manufacturers have conducted such a test program on their own canisters. Certainly each of the vehicles studied had passed the one-hour diurnal cycle from 60 to 85 degrees specified for certification under the Emission Control Act. However, since the certification procedure involves only one cycle of 25 degrees and specifies a particular test fluid, a greater temperature increase or a more volatile fuel could possibly exceed the capacity of the canisters.

Since the canister capacity could not be predicted, it is important to realize the limitation of the process of adsorption. For a given weight of adsorbent and a given surface area, the amount of material adsorbed depends on the pressure or concentration of the material around the adsorbent. The higher the pressure or concentration, the greater the amount that can be adsorbed. However, this is not a direct relationship and the percentage that can be adsorbed at higher concentrations is less than that which can be adsorbed at lower concentrations. The relation between the amount of adsorption and the concentration of the vapor to be adsorbed is represented empirically by the Freundlich adsorption isotherm

$$\frac{X}{M} = KC^n \quad (1)$$

where $\frac{X}{M}$ = amount adsorbed per unit weight of adsorbent

C = concentration (or pressure) of vapor around the adsorbent

K and n = constants which are experimentally determined.

A typical adsorption curve will have the shape shown in Figure 5-2. This figure shows that it would be possible to exceed the adsorbing capacity of the carbon under conditions where the concentration of the vapor in the canister is high, as might happen from the vaporization of a fairly volatile gasoline at higher than expected environmental temperatures. When the capacity of the carbon is exceeded, the excess vapor must be contained

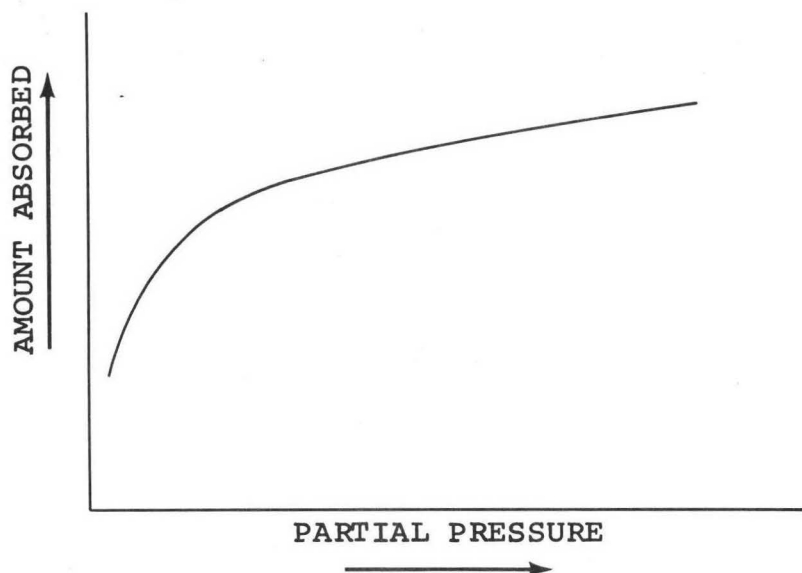


Figure 5-2. Typical Freundlich Adsorption Isotherm.

somewhere in the system or, if sufficient pressure is generated, be expelled from the system.

This situation apparently caused the fire problem in the early Pintos. Several destructive fires were ignited in the Pinto air cleaner when the engine backfired. One-half of the fires occurred in California when a high-volatility gasoline designed for use in warm weather states during winter months encountered unseasonably warm weather. Apparently, the carbon in the canister was very near or above its adsorbing capacity for fuel vapors, resulting in a large flow of fuel-rich air into the air cleaner when the engine was started. It is also possible that the excess fuel vapors being drawn into the engine might have contributed to a higher incidence of backfires, although this is difficult to assess without knowing the characteristics of the engine in detail. In either case, the vapors formed a flammable fuel-air ratio in the carburetor and air cleaner which was ignited by the backfires. The plastic air cleaner used in the Pinto undoubtedly contributed to the seriousness of the fires by sustaining combustion long enough for other components of the engine compartment to catch fire. As noted in Section 4.2.2, Ford recalled all of its Pintos manufactured before March 1971 and installed a metal plug in the vapor hose inlet in the air cleaner to reduce the inlet orifice to 1/8 inch, thus reducing the vapor flow to the engine.

This retrofit should certainly reduce the problem but whether it will completely eliminate it cannot be determined at this point. Whenever fuel vapors are routed to the air cleaner,

as in the case of the Ford cars, the possibility does exist that vapors in the cleaner could be ignited by a backfire. If the system is properly designed to function effectively with the engine, however, this possibility can be reduced to a minimum. This is apparently the case with the other Ford cars which contain a larger engine. Whether any problems will exist as the engines begin to wear and lose efficiency cannot be estimated.

One other factor that undoubtedly contributed to the problem was the reduction of the Ford canister size from the 1970 to the 1971 models. This reduction in size resulted in a 15-percent drop in the amount of carbon used as adsorbent. The additional adsorbent in the larger canisters would have reduced and possibly would have eliminated the problem.

Some other vehicles also route the fuel vapors from the canister to the air cleaner and then to the engine. This is the case for the Volkswagens and for the Plymouth Cricket. General Motors also routes the vapors released from the charcoal to the air cleaner, but this occurs only above engine idle. The majority of the vapors are routed directly to the base of the carburetor through the PCV line. All the other vehicles either route the fuel vapors into the intake manifold, the PCV system, or the base of the carburetor.

The systems that run the fuel vapors directly to the engine manifold or carburetor appear safer than those with routing to the air cleaner for the following reasons: (1) less likelihood that some of the vapors will accumulate in an uncontrolled space, such as the air cleaner; (2) less chance of forming a flammable fuel-air mixture with vapors that might be trapped because of a limited air supply in the manifold or carburetor as compared to the air cleaner; and (3) less likelihood that combustion of any fuel-air mixture in the manifold will spread to other vehicle components.

If the vapor line between the fuel tank and the storage container is blocked for any reason, a pressure buildup will occur in the fuel tank as the temperature rises due to the generation of vapor. One such condition did occur during the extreme temperature tests conducted during this program (Appendix C). An AMC Rebel containing a full tank of fuel was parked at a 20-degree angle on an approximately 12-degree slope. This resulted in the left wheel being approximately 2-1/2 inches below the right wheel and the front wheels approximately 12 inches below the rear wheels. As the vehicle sat in the warm sun, the fuel temperature rose approximately 16°F (from 87 to 103°F). When the filler cap was removed at the higher temperature, fuel poured out at such a rate that approximately 1 quart was lost before the cap could be replaced.

Examination of the Rebel fuel system schematic (Figure 4-45) will disclose the reason for this pressure buildup. The needle check valve, which closes when fuel is forced into it, is located on the left side of the vehicle, as is the filler containing the pressure-vacuum relief valve. The position of the Rebel during this test blocked both of these avenues of vapor escape, thus raising the pressure in the fuel tank. It is entirely possible that pressure in the tank could increase to a value which would force release through the filler cap, causing considerable leakage. This situation would not occur except in those circumstances where fluid was backed up against both the check valve in the vapor line and the filler cap. It should be noted that the same condition could not occur in the AMC vehicles with the filler in the rear and the check valve in front of the fuel tank. Although it would still be possible to block the liquid check valve and prevent vapors from going to the crankcase storage area, the excess vapor would be expelled through the pressure relief valve in the filler cap.

5.2.2 Multiple Diurnal Soaks. Whenever the vehicle is operated, the system is purged of any vapor within it, and therefore has maximum capacity available for the next soak period. However, if the vehicle is allowed to sit for several days without being run, the vapor generated during each soak period will accumulate in the system. Thus, the vapor storage capacity of most of the systems could be exceeded during multiple diurnal soaks even though the storage capacity is sufficient for extreme temperature rises during a single soak period. The Toyota system is the only one studied in which this could not occur. The Toyota stores its vapors in a storage tank connected by hoses to the expansion and fuel tanks (see Figure 4-51). Thus, all the vapors generated during temperature rises will remain in the system and condense back to liquid fuel as the temperature drops, so there is no cumulative vapor generation over multiple soak periods. The other systems physically remove the vapors as they are generated during temperature increases, either by adsorbing them on carbon or routing them to the crankcase. The vapors generated during each soak period are thus accumulated in the vapor storage container.

Tests conducted by Chrysler Corporation (Ref 11) showed that their vapor storage capacity of 1.6 cubic feet would hold approximately 6 or 7 diurnal soaks ranging from 60 to 85°F. Although the majority of cars are driven once a day, or once every other day, there are many times when a vehicle will remain parked for a 7-day period. Thus, it is entirely possible that many vehicles will exceed their vapor storage capacity during multiple soak periods.

Should the vapor storage capacity be exceeded, the problems will be the same as those discussed in the preceding section on extreme environmental temperatures. If the system integrity is

intact, the major fire hazard would be fires started in the engine compartment by engine backfires. Any pressure increase due to excessive vapor generation would be relieved through the pressure relief provisions of the system.

The possibility also exists that a significant amount of liquid fuel could be condensed from the saturated vapor system should the temperature drop significantly. According to the Chrysler tests, 8 fluid ounces of fuel could be obtained from the amount of vapor generated during 10 diurnal soaks. This, however, would be the amount of fuel should all of the vapor condense. This would take an extremely low temperature for a liquid as volatile as gasoline, and thus the amount of liquid fuel to be found throughout the system would be considerably less than this amount. As in the case of the vapor, as long as the system integrity is intact, this liquid fuel should pose no problem and will vaporize whenever the temperature is raised or when the engine is running and the entire system is purged of vapor. Any fuel which is dissolved in the crankcase oil (in the case of crankcase storage) should pose no particular fire problem although it could conceivably lead to accelerated engine wear.

5.2.3 Extreme Vehicle Attitudes. Extreme vehicle attitudes which could be encountered under operating conditions might be as high as a 30-degree pitch up or down or a 20-degree roll to either side. These conditions could occur either while the vehicle was moving or while it was parked. The two factors which must be considered are adequate venting of the fuel tank regardless of its attitude and preventing liquid fuel from running through the vapor line to the storage container.

All of the fuel systems examined during this program vent the fuel tank from both sides, from the front and rear, or from the center of the tank using various vent configurations. Thus, all of the tanks are provided with adequate vapor venting for all operational attitudes as long as the vapor lines are not blocked.

When the vehicle enters an other than level attitude, some of the vent lines will contain fuel. Therefore, provisions must be made for preventing the fuel from flowing through the vent lines and into the vapor line leading to the vapor storage container. All of the vehicles examined, with the exception of the American Motors vehicles, provide a liquid-vapor separator to prevent fuel from entering the vapor line. The American Motors vehicles use a liquid check valve to prevent fuel flow. The use of a check valve will certainly prevent the flow of fuel through the vapor line but, as has been seen, if the vehicle attitude is such that fuel closes the valve, the only avenue for vapor escape is through the pressure-vacuum relief valve in the filler cap. If this is blocked, fuel leakage can occur due to the pressure buildup. Even if the pressure relief filler cap is not

blocked, vapors will be emitted through the cap during temperature rises and will compromise the effectiveness of the evaporative emission control system.

The 1970 General Motors passenger cars also use a liquid check valve which is located in the liquid-vapor separator. However, the design of the separator precludes the closed valve from completely blocking vapor flow (see Figure 4-23). The check valve is contained in the lower compartment of the separator, which also contains the outlets for the front fuel tank vents. The check valve thus prevents fuel flow through the separator when the vehicle is in a nose-down attitude. The rear vent line, which would be above the fuel level in this attitude, feeds into the upper chamber where the vapor line outlet to the canister is also located. Thus, the separator will never be blocked completely by fuel.

A majority of the vehicles examined use a standpipe liquid-vapor separator. The vent lines from the fuel tank rise vertically inside the separator with their outlets near the top of the separator. A drain is provided in the bottom of the separator which allows any liquid fuel which has entered to drain back to the fuel tank. The outlet for the vapor line to the vapor storage container is located at the top of the standpipe and very often contains a small orifice. This arrangement assures that no fuel can enter the vapor line unless the separator is completely full. The sizes and locations of the separators in the vehicles would prevent this from happening during any vehicle attitudes that might normally be encountered.

Those vehicles which use an expansion tank to separate the liquid fuel from the vapors are also satisfactory for extreme operating attitudes because of the tank's location well above the fuel tank and the fact that the vapor lines to the storage container exit the top of the expansion tanks.

The liquid-vapor separator used in the 1971 Ford vehicles is unique, consisting of a foam baffle assembly (Figure 4-11) mounted on the top near the center of the fuel tank. Although fuel could enter the separator in some vehicles when the car is in a pitched attitude greater than 15 degrees, no fuel leakage through the separator was observed in the pitch tests conducted under this program (Appendix D), even when the vehicle was pitched to 60-degree attitudes. Apparently the small (.05-inch diameter) orifice in the separator is sufficient to prevent fuel flow from the separator into the vapor hose.

Vertically-mounted tanks such as those in station wagons and in some pickup trucks do not need a liquid-vapor separator, as proper routing of the vapor line and its exit from the top of the tank assures that the vent line will always be higher than any liquid level in the fuel tank.

Many of the vehicles contain pressure-vacuum relief valves in the filler cap. None of these pressure valves will open below 1/2 psi, which corresponds to approximately an 18-inch head of gasoline. Calculations show that the pressure from a long flat tank, even at a 30-degree angle which would back the liquid fuel up against the filler cap, would not be sufficient to open the valve and allow spillage.

The only hazard noted under conditions of extreme operational vehicle attitudes was that already discussed for the Rebel in Section 5.2.1. Accident conditions in which the vehicle comes to rest in a pitched attitude greater than 30 degrees will be discussed in Section 5.3, Crash Conditions.

5.2.4 Severe Maneuvering Forces. Severe maneuvering forces which can be encountered during vehicle operation may be as high as .7G for braking and acceleration and .4G for cornering. When these maneuvering forces are encountered, the fuel in the fuel tank is subjected to an acceleration and the surface of the liquid tends to assume an angle corresponding to the equation

$$\tan \theta = \frac{x}{g} \quad (2)$$

where the maneuvering force acceleration is x and g is the acceleration of gravity. According to the above equation, the surface of the fuel in the fuel tank would tend to assume a 35-degree angle for acceleration or deceleration and a 22-degree angle for cornering. Thus, the application of severe maneuvering forces creates a situation analogous to that discussed above for extreme vehicle attitudes where fuel is forced into the liquid-vapor separator or against the filler cap, depending on the direction of application.

Assuming that the entire head of fuel generated during a .7G acceleration is directed against the pressure-vacuum filler cap, a pressure of slightly over 1/2 psi could be exerted on the cap. Thus, it might be possible to force a small amount of fuel out of a pressure relief valve set at 1/2 psi. However, since the filler caps are generally above the liquid of the fuel tank during normal attitudes, the actual pressure exerted would be somewhat less and no spillage should occur from the relief valve during operational accelerations. The liquid-vapor separators found in the vehicles analyzed should also be adequate to handle all maneuvering forces.

One hazard that was uncovered during severe maneuvers occurred in the VW Super Beetle. As noted in the description of the Super Beetle fuel system (Section 4.6.3), the filler cap is provided with a mechanical stop to prevent damage from over-torquing the synthetic polymer threads of the cap. Although the mechanical stop is a good idea from a maintenance standpoint, the

design is such that the filler cap cannot be screwed tightly into the fuel tank, as shown in Figure 5-3. Thus, the filler cap gasket is not seated firmly against the tank opening and leakage occurred around this gasket when the Super Beetle was subjected to severe cornering with a full tank of fuel.

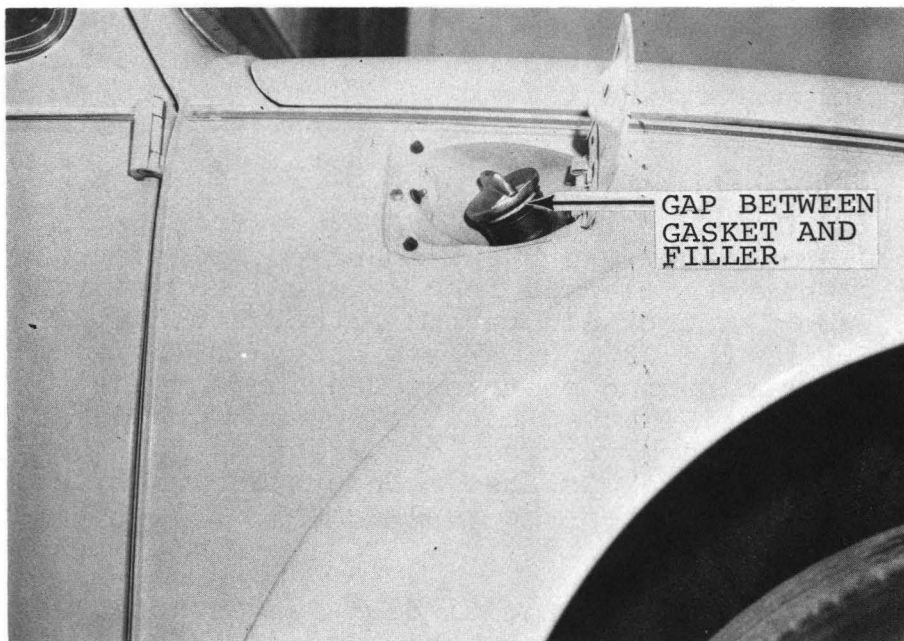


Figure 5-3. Filler Cap Installation in 1971 VW Super Beetle.

5.2.5 Environmental Degradation. Environmental degradation of a component occurs due to chemical attack on the component material, such as salt corrosion of metals or ozone attack of synthetic materials. Such chemical attacks on the material generally proceed at a slow rate and often do not show up until several years after the manufacture of the vehicle.

A specific assessment of the resistance to degradation of the materials used in the fuel systems could not be determined without extensive laboratory tests. Neither could the specific effects of aging be determined since the vehicles examined were all no more than a year old. However, the vehicles were examined for any signs of degradation and were also analyzed for the proximity of polymer materials to a heat source since heat will increase the rate of aging.

Three instances of material deterioration were noted during the vehicle analyses; one involving the corrosion of metals and the other two involving the deterioration of polymeric substances.

The one instance of metallic corrosion was noted in a Ford Pinto. The inside of the filler cap, as well as the inside of the filler pipe, exhibited a great deal of what appeared to be salt corrosion. The rubber gasket sealing the filler cap showed a minor amount of corrosion but this did not interfere with sealing the tank. Although no detrimental effects were noted from the corrosion at this particular time, the severity of the corrosion indicated that it could become appreciable over a time span of several years. Should this happen, it is entirely possible that the pressure-vacuum relief valve located in the filler cap could be prevented from opening due to the corrosion of the metal parts surrounding the valve.

The hazards involving polymeric materials which were noted during the analyses both involved rubber hoses in the fuel systems. The large diameter rubber hose in the fuel tank filler neck of a 1970 Ambassador was deeply checked, possibly due to ozone attack. This vehicle had been received for a front-end barrier test under another contract. Although the filler neck did not leak during the 30 mph barrier test, it was so weak that it was easily broken during post-test handling of the vehicle. Thus, it is very possible that the filler neck would have broken during a rear end crash or a crash occurring in the rear quarter panel where the filler was located. Undoubtedly the passage of time would have necessitated the replacement of the filler neck to prevent leakage.

The other instance of material degradation noted was found in a 1971 AMC Hornet. The vapor hose leading from the fuel tank to the liquid check valve had been burned almost through where it had come in contact with the tail pipe, as shown in Figure 5-4. (The vehicle odometer registered 4,281 miles at this time.) In addition to the loss of vapor through this line, liquid fuel could also be lost since the break occurred between the liquid check valve and the fuel tank.

This vehicle was one that had been selected to undergo the pitch tests conducted during this program (Appendix D). No fuel was lost until the vehicle was pitched more than the operational limit of 30 degrees, but there was evidence from the condition of the vehicle undercoating that fuel had been forced through the hose during sudden braking maneuvers. Although the tail pipe temperature would not be sufficiently high to ignite the fuel or vapor, the possibility of an outside ignition source must always be considered.

Several instances were noted where rubber or plastic vapor lines were routed in close proximity to heat sources. For example, the rubber vapor line from the fuel tank to the liquid-vapor separator in the 1970 Dodge Polara was located approximately 3 inches from the tail pipe. An even more hazardous situation was noted in the 1970 Mustang Mach I where the rubber vapor

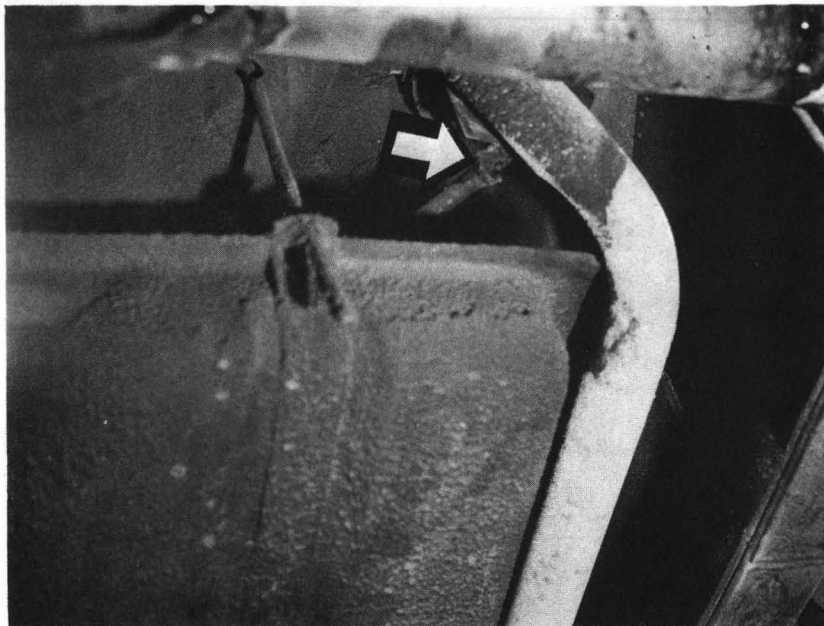


Figure 5-4. Burned Vapor Hose in 1971 AMC Hornet.

line from the control valve to the canister was routed approximately 1 inch away from the exhaust manifold in the engine compartment. This line actually came in contact with a bracket mounted on the manifold, as may be seen in Figure 5-5. In this same vehicle the plastic vapor line from the liquid-vapor separator to the three-way control valve was routed only 2 inches away from the exhaust pipe.

In general, emission system components made from rigid plastic can be considered fairly safe from environmental degradation. These parts include the liquid-vapor separator found in the 1970 Ford, the canisters found in the 1970 and 1971 General Motors vehicles, and the liquid-vapor separator contained in the 1970 General Motors vehicles.

The degree of hazard which occurs from material degradation depends on the component and the location where the degradation occurs. If a vapor line between the fuel tank and the liquid-vapor separator fails, leakage can occur from the fuel tank under severe maneuvering conditions, as was seen in the Hornet. The same hazard would be present in the failure of a filler neck.

A failure in a vapor line leading from the separator to the storage container would release vapor to the surrounding atmosphere. This is probably not too hazardous if the line break is located underneath the car where the flow of air as the car is moving will sweep the vapors away. When the car is not moving, vapors would tend to accumulate under the car, but this would

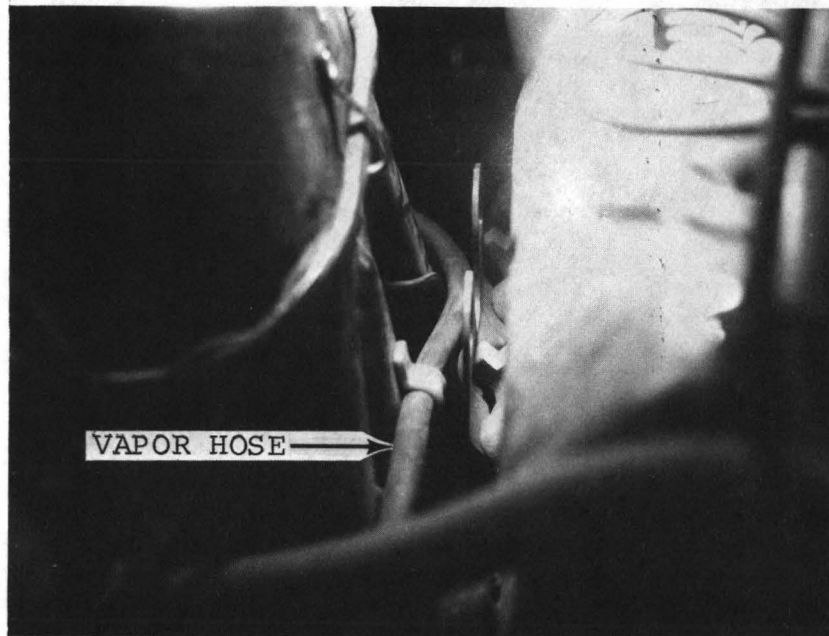


Figure 5-5. Vapor Hose in Engine Compartment of 1970 Ford Mustang.

certainly be no more of a hazard than the atmospheric venting of the pre-evaporative emission control vehicles. However, should the vapors be released into an enclosed area, the degree of hazard rises considerably. Vapors could be emitted into the luggage compartment of vehicles containing vapor lines in this compartment, such as the 1970 Ford Mustang, Maverick, and Cougar; the Toyota Corolla; and the Volkswagen Beetle. Vapors trapped in these compartments could form a flammable fuel-air mixture which could be ignited by ignition sources such as matches, lighted cigarettes, or short circuited wires, as well as the numerous ignition sources present during a collision. One factor that tends to lessen this hazard significantly is that these lines are in a closed compartment and thus protected from the environment. Material degradation should not be as prevalent as for those components which are exposed to the environment.

Failure of the vapor lines in the engine compartment does present a serious hazard since the vapors evolved could be trapped near many ignition sources. Although most of the vapors would be ventilated from the engine compartment while the vehicle was moving, the vapors could accumulate whenever the vehicle was standing still, whether the engine was running or not.

The surface temperature of the engine and the exhaust manifold would not be sufficient to ignite the vapors. However, an electrical spark from any source could easily ignite a flammable fuel-air mixture in the engine compartment. Such sparking would

not ordinarily occur if the electrical wiring in the engine was maintained in satisfactory condition. However, should the wiring insulation be compromised due to aging, sparking between wires could well become an ignition source for the trapped vapor. This type of hazardous situation can easily be conceived when starting an older car. In such a case, sparks might be generated from worn starter brushes in the starter motor or from worn ignition wires in any part of the circuit.

5.2.6 Vibration. Vehicle vibration can lead to three failure modes: (1) fatigue failure of metals or plastics, (2) the loosening of attachments and connections, and (3) the chafing of components as they vibrate against the vehicle structure.

No evidence of fatigue failure or attachment loosening was evident in any of the vehicles analyzed. This is not surprising due to the newness of the vehicles. In general, the components and their attachments seem adequate from the standpoint of fatigue or vibration failure. However, one potential problem does exist that should be studied in further detail. Vehicle fires have been started in the past when force-fit plugs located in the carburetor body have been forced out due to vibration, allowing fuel to spill on the hot engine and thus start an engine compartment fire. The problem of the force-fit plugs still exists as they are used in the 1970 and 1971 carburetors. This problem is particularly aggravated if a fairly large force-fit plug is located next to the fuel line inlet, as shown in Figure 5-6. Pressure from the incoming fuel can force the loosened plug out, allowing fuel to be pumped through the opening and onto the hot engine before the vehicle driver is aware of the problem.

Although the failure of a component due to chafing is also a long term process, careful examination of the vehicle can disclose areas where chafing could occur and thus present a problem. Damage which had already occurred because of chafing was found in the 1970 Pontiac Catalina. In this vehicle, which had an odometer reading of 15,198 miles, chafing of the vapor emission hose from the liquid-vapor separator to the canister and of the vapor return line from the fuel pump to the fuel tank was readily apparent, as shown in Figure 5-7. The serious wear of these lines was caused by the chafing of the lines on the differential gear housing. Another potential chafing problem was found in the same vehicle in the engine compartment where the hose from the carbon canister to the carburetor came in contact with the air conditioner compressor bracket, as seen in Figure 5-8. This line is supported only by being taped to another line in the engine compartment. After the vehicle had been driven for this many miles, the tape had dried and come off. The tape marks may still be seen in Figure 5-8.

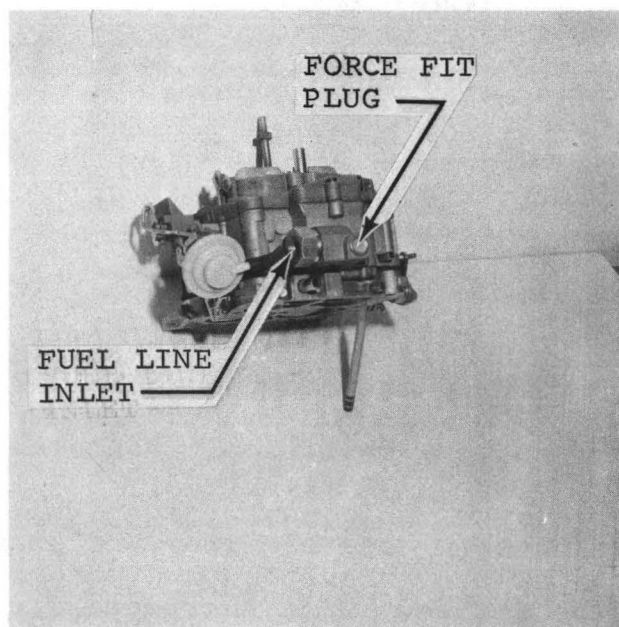


Figure 5-6. 1970 Carburetor Containing Force Fit Plug.

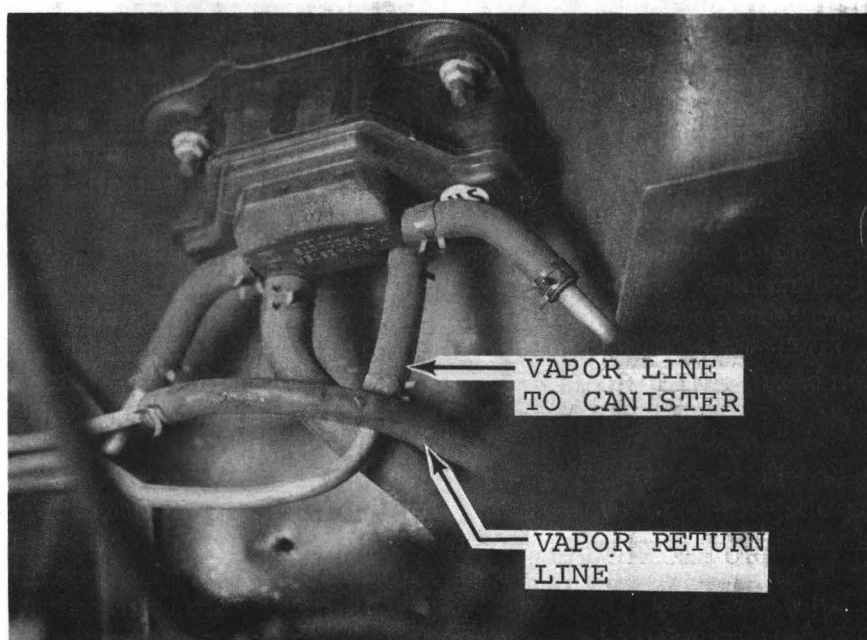


Figure 5-7. Chafing of Vapor Hoses in 1970 Pontiac Catalina.

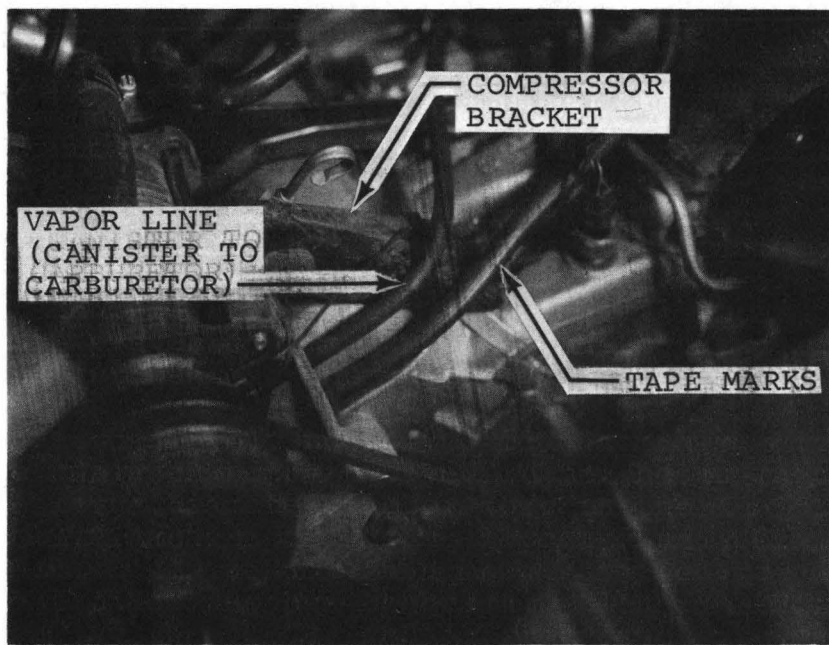


Figure 5-8. Engine Compartment Vapor Hose Routing in 1970 Pontiac Catalina.

Several other potential chafing hazards were discovered during the analyses. One of these exists in the 1971 VW Super Beetle where the vapor line in the luggage compartment is routed over and rides on the luggage compartment lid hinge. In the 1971 Impala the vapor line from the liquid vapor separator to the canister rubs along the front lower control arm mount, as shown in Figure 5-9.

All of the potential chafing problems involved vapor lines. None of the other components of the system exhibited any readily noticeable potential for chafing. The potential for chafing in the lines is greater than for any of the other components because of the length of the lines, necessitating the routing of the lines around many other vehicle components. In addition, the unsupported lengths of line between structural clamps allows them a fair amount of freedom to vibrate against adjacent structures.

The manufacturers are not insensitive to this problem, however, and the lines are generally well supported to reduce vibrational movement to a minimum. Special precautions to prevent chafing have been taken in many instances. For example, in several General Motors vehicles metal coils have been wrapped around the line, as shown in Figure 5-10, to protect the line in potential chafing areas. Another example of such protection is found in the Ford Pinto where the reinforced paper purge line from the canister to the air cleaner is stabilized by a loose clamp on the radiator, as seen in Figure 5-11. The chafing

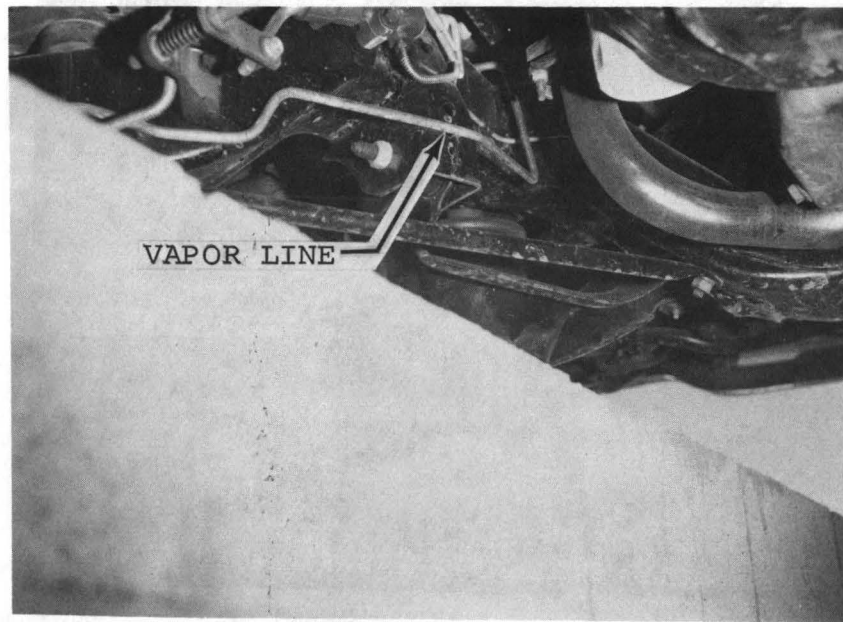


Figure 5-9. Vapor Line in 1971 Chevrolet Impala.

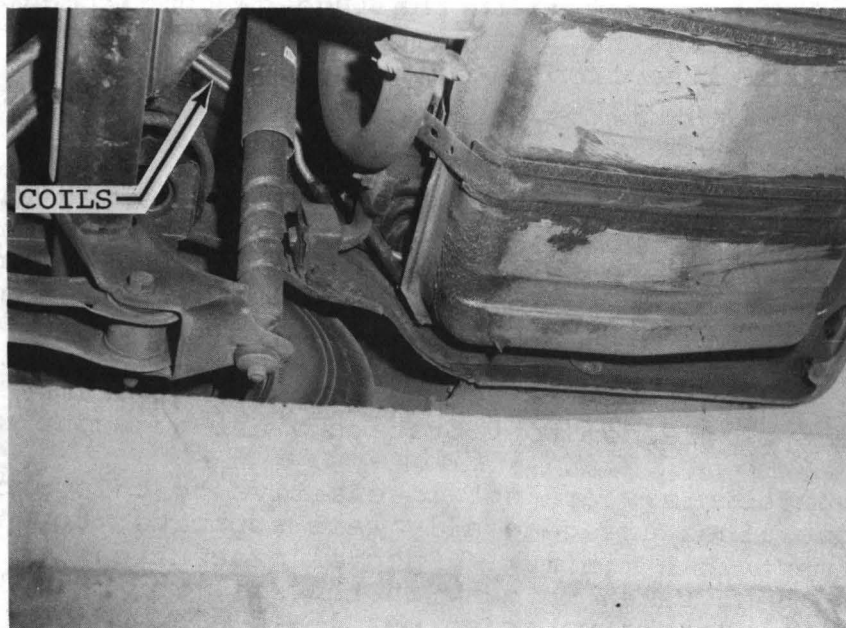


Figure 5-10. Metal Coil Protection on 1971 Vega Vapor and Fuel Lines.

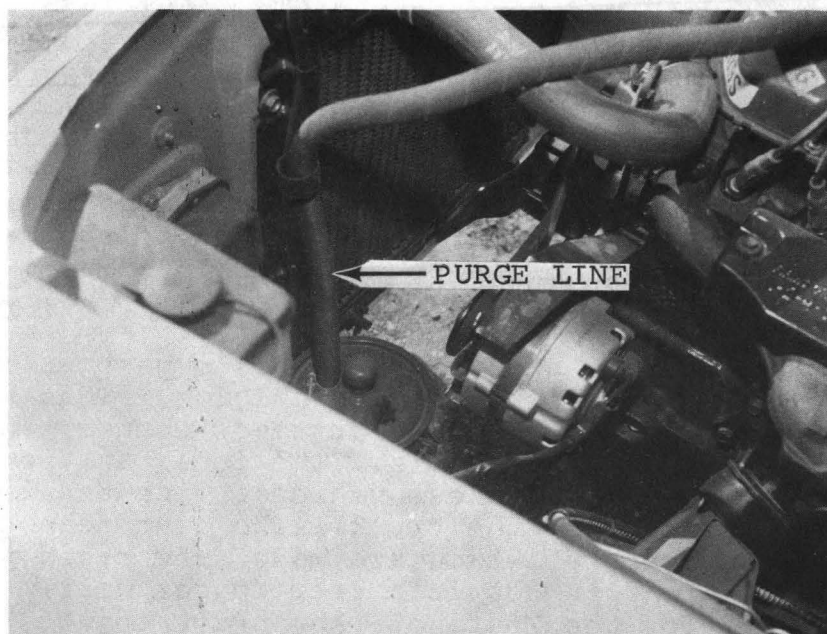


Figure 5-11. Vapor Purge Line Installation in 1971 Pinto.

hazard of this design has been reduced to a minimum by coating the clamp with a smooth synthetic material to eliminate any sharp edges.

The hazards generated by the failure of the vapor lines due to chafing are identical to those discussed previously under Environmental Degradation.

5.2.7 Foreign Object Damage. Foreign object damage may occur to any evaporative emission control system components which are in an exposed location. Foreign object damage may occur to those components located in wheel wells, at the bottom of the engine compartment, and underneath the car from road hazards, especially from rocks thrown up by the tires. Foreign object damage may also occur to exposed components in the luggage compartment from compartment contents, especially during a collision.

There are several components in the evaporative control systems analyzed which are exposed to road hazards because of their location. Two such components are the carbon canisters in many of the Ford vehicles, which are located very low in the engine compartment, and the carbon canisters in the Volkswagens, which are located in the fender well. However, both of these canisters are made of metal and are fairly sturdy. In addition, the hoses leading to the canisters seem adequate to resist rock and gravel damage.

Vapor lines routed under the car could possibly be subjected to flying rocks and gravel, but the routing of most of the hoses is such that they are fairly well protected by other vehicle components from such damage. Many of the most exposed lines under the vehicles are made of metal and should not sustain damage. Several vehicles, such as the 1970 Dodge, the 1971 Satellite, and the Chevrolet Station Wagon, use lightweight splash guards to protect their hoses in the fender wells. Thus, although the possibility exists that road damage could occur to some of these components, the hazard must be considered small.

Component damage from shifting luggage compartment contents, however, does pose a hazard in several vehicles. This hazard is particularly severe in the 1970 Ford Mustang, Cougar, Fairlane, Montego, and Maverick passenger cars. The fuel tank is bolted into the trunk area in all of these vehicles with the top of the tank serving as the floor of the trunk. The vent connections and the liquid-vapor separators, which are made from rigid plastic, are in exposed positions in the left rear fender well, as may be seen in Figure 5-12 for the Mustang. Any heavy object, such as a tool box, thrown against the vent connector or the liquid-vapor separator could easily damage these components and leakage could result. This leakage would allow vapors to accumulate in the trunk compartment and, during sharp cornering to the left or a vehicle attitude resulting in the left side lower than the right, could also result in liquid fuel spillage. This spillage could be trapped around the well surrounding the perimeter of the fuel tank and be carried in this position under the rubberized mat covering the fuel tank top for some time before it would evaporate. This could pose a hazard for the unwary person opening the trunk or a very definite hazard during a rear-end collision with its attendant ignition sources.

It should be pointed out, however, that Ford has eliminated this hazard in its 1971 models. The Mustang, Cougar, Maverick, and Comet vehicles now have the fuel tank located under the trunk floor pan area and there are no evaporative control system components present in the trunk. The Torino and Montego, although the top of the fuel tank still forms the bottom of the trunk floor, no longer have any of the vapor system components located in the trunk. Thus, the danger is no greater than has been present in these vehicles for the last several years.

There are several vehicles in which vapor lines between the fuel tank and the liquid-vapor separator are exposed in the luggage compartment area. These include the Volkswagen Beetle, Karmann Ghia, and Super Beetle and the Dodge Colt. Of these, the most hazardous must be the Dodge Colt where the vapor lines between the fuel tank and the expansion sub-tank are routed up through the left side of the trunk. Although these flexible lines would not likely be broken by the trunk contents, they could certainly be pulled loose. This would allow vapors to

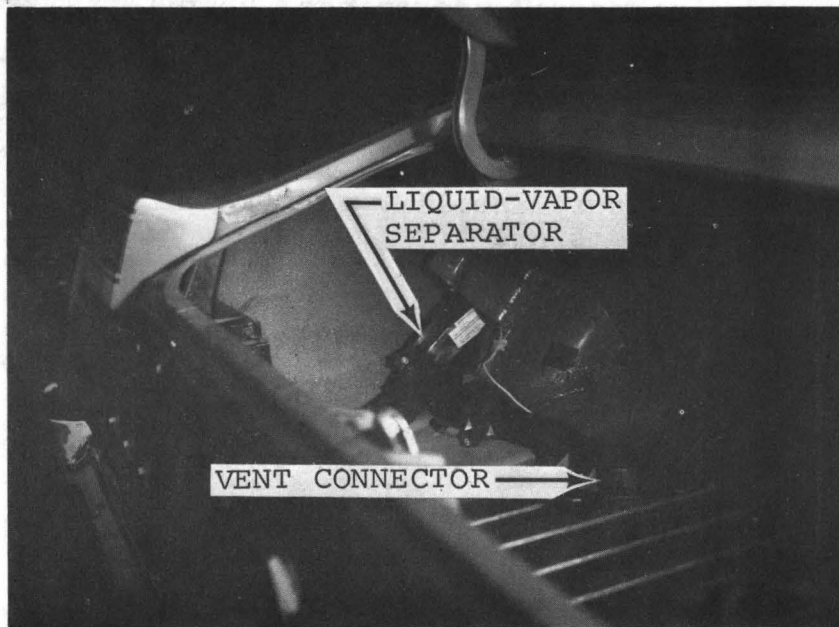


Figure 5-12. Vent Connector and Liquid Vapor Separator in 1970 Ford Mustang.

escape into the trunk and be trapped there, possibly to form a flammable fuel-air mixture. Should the line between the tank and the sub-tank be pulled loose, fuel surges or fuel expansion could lead to liquid fuel being spilled in the trunk area.

The vapor lines in the Volkswagens are routed fairly well out of the way and near the back of the luggage compartment where possible. The lines in the Super Beetle are not as vulnerable as those in the other Volkswagens because the placement of the fuel tank in the rear of the luggage compartment shortens the length of the vapor hoses, leaving less of them exposed to contact with trunk contents. The other Volkswagens, however, contain several lengths of hose which could be pulled loose by the trunk contents impacting the hoses. Should any of these hoses be pulled loose, the same situation would exist as discussed for the Colt, in that vapor or, under some conditions, liquid fuel could be spilled into the luggage compartment.

There are several liquid-vapor standpipe separators located in the luggage compartment of vehicles which could be struck by the trunk contents. These are found in the Plymouth Cricket, the 1970 Ford sedans, the 1970 and 1971 Chrysler vehicles (with the exception of the 1971 Plymouth Satellite), and the 1971 General Motors vehicles. However, the location of these separators and the fact that all but the Ford separator are made of metal leads to the conclusion that these components would not be damaged by

trunk contents during normal operational conditions, although they might possibly be damaged by loose trunk contents during a collision.

5.2.8 Component Malfunction. Most of the components in the evaporative emission control systems are passive, which is certainly desirable from a reliability standpoint. The only active components in the systems are the pressure-vacuum relief valves, purge valves, and liquid check valves. The pressure-vacuum relief and purge control valves are spring-loaded, pressure-differential-type valves, while the liquid check valves are float-and needle-type valves. Both of these valve types are simple in design and operation and should pose no great reliability problems. However, the effect of a malfunction must be considered as even the most reliable valves will sometimes fail.

A malfunction of the pressure-vacuum relief valve located in the filler cap could lead to the valve remaining open or closed at all times. A major consequence of the valve being stuck open would be the defeat of the evaporative control system, allowing fuel vapors to escape into the atmosphere. A more serious consequence would occur during crash conditions since fuel could be forced through the open valve by impact surges or by the vehicle rolling over. If the valve is stuck in the closed position, the formation of a vacuum as fuel is being used could result in the collapse of the fuel tank. A more serious consequence would be an increase of vapor pressure in the tank during prolonged hot soak periods if the vapor vent line was blocked for any reason. This increased pressure could force liquid fuel into the liquid-vapor separator or, in the American Motors vehicles, from around the filler cap.

The three-way control valve in the 1970 Fords actually consists of three separate valves: a vapor relief valve, a vacuum relief valve, and a safety pressure relief valve. Of these valves, a malfunction of the vapor relief valve would lead to the most hazardous situations in that fuel tank pressurization could occur with the valve stuck in the closed position, or fuel tank overfilling could occur with the valve stuck in the open position. The only consequences of the pressure or vacuum relief valves being open would be the loss of some fuel vapors to the atmosphere. If the vacuum relief valve remains closed, the fuel tank could collapse as fuel is used. Permanent closure of the pressure relief valve would cause no problems unless the vapor line to the canister was blocked.

Should the purge control valves found in the Toyota or the Dodge Colt fail to open during engine operation, the capacity of the Toyota storage tank or the Colt canister could be exceeded in a short time. This would not be particularly hazardous in the case of the Toyota, as the excess vapors would exit through the air filter in the rear of the car. However, in the Colt the

excess vapors would exit through the canister into the engine compartment and could present a hazardous situation. If the valves remain open in either car, no particular hazard would result as the lines from these valves are both routed directly into the intake manifold of the engine.

A malfunction of the purge valve located on top of the Chevrolet and some of the Oldsmobile canisters could result in the undesirable situation of fuel vapor being released into the engine compartment. Should the purge valve remain in the closed position while the engine is running, the carbon will not be purged of the adsorbed vapor and its capacity will be exceeded. The excess vapor would then be vented through the bottom of the canister to the atmosphere. Should the valve remain open, no particular hazard would occur as the vapors would be adsorbed in the carbon and then purged while the engine was running.

The same situations would exist if the valve on the Pontiac canister malfunctioned. However, the Pontiac vacuum relief also comes through this canister valve and, should this part of the valve malfunction, fuel tank collapse could occur.

Malfunctioning of the liquid check valves found in the American Motors vehicles and the 1970 General Motors vehicles could lead to fuel tank pressurization or fuel flow into the vapor lines. The pressure buildup could occur in both vehicles if the valves were stuck in the closed position. This would occur at any attitude in the American Motors vehicles, but would occur in the General Motors vehicles only when the rear tank vent was below the liquid fuel surface. Both of these vehicles incorporate pressure relief valves in the filler cap, but this valve would be blocked in the General Motors vehicles with the car in the attitude necessary to submerge the rear vent. Blockage could also occur in some attitudes with the AMC vehicles, as was noted in the Rebel.

If the check valves were stuck in the open position, fuel might be allowed into the vapor line if the rear end of the vehicle was elevated. The flow rate would be minimal, however, due to the small orifices at the vapor line outlets in both vehicles.

5.2.9 Maintenance Errors and Omissions. One of the most common maintenance errors which can be foreseen with the evaporative emission control systems is the replacement of the filler cap with one of the wrong type. Ordinary fuel tank filler caps are available not only at auto parts stores but in many filling stations and discount stores. It is entirely possible that the operator of the vehicle would not realize the importance of replacing the cap with one of the original type and might not even realize that a special cap was necessary. Should the filler cap be replaced with a vented cap, no particular hazard would result. The main consequences would be the defeat of the evaporative

emission control system and possibly less than optimum engine performance. However, should the motorist replace a filler cap incorporating a pressure-vacuum relief valve with a non-vented filler cap, he may end up with a collapsed fuel tank or fuel spillage due to a pressure buildup if the fuel tank vapor vent line is blocked for any reason. It should be noted that in some vehicles replacement with a wrong filler cap would be unlikely. For instance, the filler cap in the Ranchero, Pinto, Cricket, and Mustang form a part of the outer decor of the vehicle and would, therefore, more than likely be replaced with a similar cap. The double-locking filler cap now in use in the 1971 General Motors vehicles is also sufficiently different from the older, non-vented caps to discourage their use.

Another maintenance error which could prove hazardous involves the fuel tanks of the 1970 Ford Cougar, Fairlane, Maverick, Montego, and Mustang. The internal vents in these fuel tanks are made from plastic and steam-cleaning, soldering, or welding the tanks would probably damage these plastic vents. Since these are standard methods for repairing or cleaning fuel tanks, and since many shops besides authorized Ford dealers do this kind of repair, it is conceivable that such an error could easily occur through ignorance of this unique situation on the part of repairmen. Should the tank vents be closed due to such a procedure, a very hazardous situation could develop since these tanks contain non-vented filler caps with no provision for pressure relief. It is quite conceivable, therefore, that a fairly high pressure could build up in the tank and eventually lead to considerable fuel spillage around the filler cap or, even more hazardous, to a pressurized fuel tank which, if ruptured during a rear-end impact, would spray fuel and fuel vapor for a considerable distance. This particular hazard exists only for the 1970 models of the vehicles named. Ford has since eliminated the plastic vents and all of their 1971 fuel tanks may now be cleaned and repaired in the standard manner.

Another maintenance error which could easily occur is the inadequate or improper connection of the vapor hoses. Vapor would be allowed to escape at any point in the system where the hose connection was not tight. For instance, there was a noticeable odor of gasoline vapor in the trunk of the 1970 Mustang which was undoubtedly due to a poor vapor hose connection. Vapor leakage could be especially dangerous in either the luggage compartment or the engine compartment, as was pointed out in a previous section. It would be even more hazardous in the cab of a pickup truck where a lighted match could ignite a flash fire of the escaping vapor with catastrophic results for the occupants.

In general, the improper routing of the purge hoses from the canister to the engine would result in nothing more than poor engine performance. However, should the vapor hoses between the fuel tank and the liquid-vapor separator be improperly routed,

serious consequences could occur. For instance, should one of the tank vents be connected to the liquid-vapor separator outlet and the vapor line to the canister be connected to one of the forward tank vent outlets, a considerable amount of fuel could flow into the engine compartment during a nose-down vehicle attitude.

One example of such a possibility may be found in the 1970 General Motors cars where the vapor separator connections for the left forward fuel tank vent and the vapor line to the carbon canister are the same size and are located only 2-1/2 inches apart. If these two hoses were interchanged, fuel could flow directly from the right forward vent (when the vehicle was in a nose-down attitude) through the separator and hose to the canister. The fuel would flood the canister and eventually run out the bottom of the canister, thus exposing liquid fuel and fuel vapors to engine compartment ignition sources.

The possibility of routing the vapor hoses improperly is not unique to General Motors. It could occur in most of the vehicles examined with the exception of the 1971 Ford, in which the liquid-vapor separator is mounted directly on the fuel tank, and the American Motors vehicles, in which a liquid-vapor separator as such is not used. The results of such improper routing would be the same as discussed in the Chevrolet situation, i.e., liquid fuel flow through the separator and into the vapor storage container.

It should also be pointed out that General Motors has not been completely oblivious to this problem, as all of their canisters (which contain 3 or 4 hose outlets) have been designed to minimize the possibility of wrong hose connections by not only using different sizes of outlets for each hose, but also stamping directly on the top of the canister which outlet is for which hose.

Ford, Chrysler, Volkswagen, and most American Motors evaporative control systems require no maintenance. Thus, the only omission that could occur would be those of any system, i.e., not replacing or repairing worn parts when necessary. All General Motors, American Motors with V-8 engines and automatic transmission, Colt, and Toyota vehicles do require maintenance of the evaporative control system and the effect of neglecting this maintenance should be examined.

The air filters in the canisters of the General Motors and American Motors vehicles and of the Dodge Colt are to be replaced every year or every 12,000 miles of driving (more often under dusty conditions). If this is not done, the air filters could become clogged with dust and dirt, limiting the supply of air to the canister. Should this happen, the canister will not purge properly and the capacity of the carbon to adsorb the fuel vapors would be seriously compromised.

Another problem could well arise in the case of the Dodge Colt which does not have a pressure-vacuum release valve in the filler cap, as do the General Motors and American Motors vehicles. The Colt system provides pressure-vacuum relief through the canister. The canister purge line to the engine is closed by the purge valve when the engine is not running and any excess vapor must go through the canister and the air filter to the atmosphere (see Figure 5-13). Should the air filter become clogged, a fuel tank pressure increase during hot soak periods could force a considerable amount of fuel up into the sub-tank located in the trunk. This fuel would then present a definite hazard should the exposed lines in the trunk be damaged from trunk contents or crash forces. Clogging of the canister air filter would also block incoming air and could lead to a collapsed fuel tank as the fuel is used.

The air filter in the vapor storage tank purge line of the Toyota should also be cleaned every 12,000 miles. As in the case of the Dodge Colt, the Toyota system provides pressure-vacuum release through this filter. Should the filter become clogged, pressure buildup or a vacuum could occur in the tank. Partial clogging of the filter could seriously compromise the ability to purge the vapor storage tank when the vehicle is running.

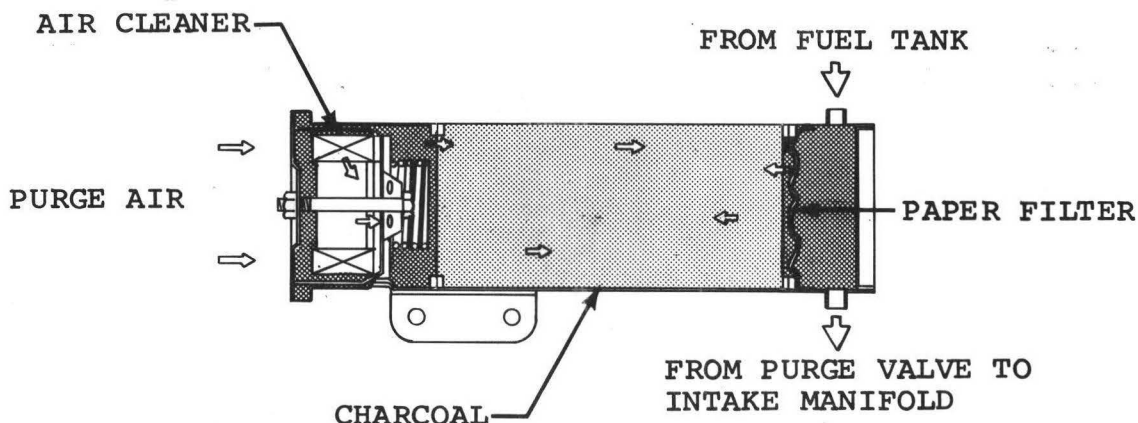


Figure 5-13. 1971 Dodge Colt Carbon Canister.

5.3 CRASH CONDITIONS

5.3.1 Front Impacts. The determination of fire hazards generated during vehicle front impacts was based on data obtained from sled and drop tests, front impact barrier tests, and actual

automobile accidents. The sled and drop tests assessed the ability of the fuel system components and their attachments to withstand crash accelerations. The barrier tests and accident analyses determined the effects of direct impacts on the components from deforming structure or other objects. The data from these tests were then extrapolated to non-crashed vehicles to determine their susceptibility to front impact damage.

5.3.1.1 Acceleration Damage. The sled tests which were conducted to assess fuel system damage due to crash accelerations are described in detail in Appendix F. Briefly, 1970 Ford, General Motors, and Volkswagen fuel system components and subsystems were subjected to front impacts at velocities of 30 and 45 mph and accelerations ranging from 38 to 60G. These conditions were chosen to simulate the acceleration pulses which could be expected during front barrier impacts at these speeds. A drop test was also conducted on Ford, General Motors, and Toyota carburetors to assess their vulnerability to the extremely high accelerations that occur during impacts in which the engine contacts the struck object. The 30 mph impact velocity of this test resulted in a peak acceleration of 295G.

None of the components were damaged during any of the tests. The only attachment failure occurred in the Volkswagen subsystem sled test when the fuel tank slipped completely out of the clips holding the tank to the vehicle structure. Complete separation from the structure was prevented by the filler neck. It is unlikely that the fuel tank would behave in this manner during a front end collision since the vehicle structure would be pushed back against the fuel tank, trapping it in the structure; this happened during a subsequent barrier impact with a 1971 Volkswagen Squareback sedan. In this test the fuel tank was buckled and pushed rearward approximately 3 inches (see Figure 5-14), but no leakage occurred either during or after impact. The strong flexible filler neck which held the fuel tank in the structure during the sled test undoubtedly contributed to the absence of leakage during the barrier test by moving with the deforming structure rather than exerting high stresses on the filler cap or fuel tank connections.

There was a small amount of leakage when the vent line from the Volkswagen tank pulled loose as the tank left its structural attachment during the sled test. However, this leakage can be discounted as a hazard since the Volkswagen fuel tank did not separate during the barrier test. The only other leakage which occurred was a small amount of fuel sprayed from around the Ford and General Motors filler caps during the sled tests. Figure 5-15 shows the fuel spray from the Chevelle filler during the front impact test. Although only a small volume of fuel was lost, the spray could travel some distance to an ignition source and must therefore be considered a potential fire hazard.



Figure 5-14. 1971 Volkswagen Squareback After a 30-mph Barrier Impact.

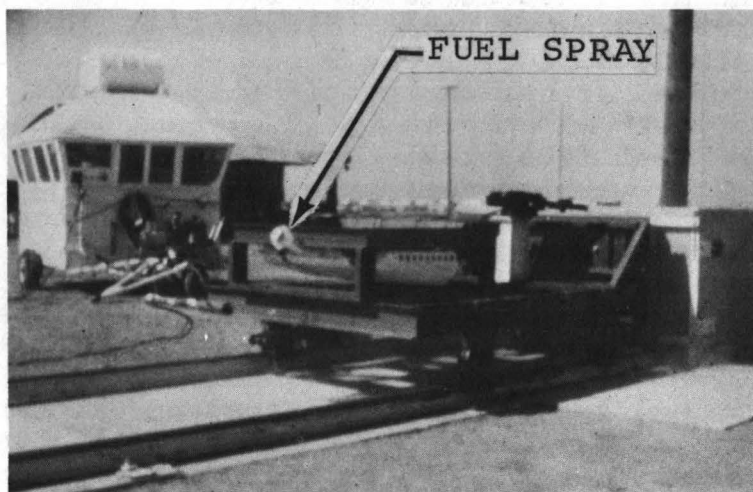


Figure 5-15. Fuel Spray During Sled Test of 1971 Chevelle Fuel System.

5.3.1.2 Impact Damage

5.3.1.2.1 Structural Damage. Twelve front barrier impact tests conducted under other programs furnished quantitative data on structural damage occurring during front end collisions. The vehicles tested and the test data for the front barrier impacts are shown in Table 5-I which also shows the wide variety of vehicles tested. The impact speed in every case was near 30 mph. Crush distances and rebound distances are also listed in the table.

Figure 5-16 shows a plot of the crush distance of the impacting vehicle versus the kinetic energy. Although it would seem logical for the crush distance to be some function of the kinetic energy of the vehicle at impact, the data in Figure 5-16 do not substantiate this. The data suggest instead that the crush distance during a front impact is more a function of the type of vehicle structure than of the kinetic energy. It would be expected that identical or similar vehicle structures would exhibit a relationship between crush distance and kinetic energy.

The data do show that the crush distance resulting from a 30-mph front barrier impact is generally from 1-1/2 to 2 feet. Examination of the vehicles revealed that in every case the engine compartment had been compressed back to the front tires with the engine generally pushed back very close to the firewall as shown in Figures 5-17 and 5-18. Thus, any component located in the engine compartment forward of the engine block would be subjected to severe impact forces, while those located beside the engine would be afforded considerable protection during a front end impact.

5.3.1.2.2 Fuel System Damage. Examination of Table 5-I shows that 6 of the 12 vehicles which were barrier tested suffered some type of fuel system damage. In 3 of the vehicles (Chevelle, 1971 Fiat, and Capri), damage was limited to the evaporative control system components. The damage in the other 3 vehicles (Toyota, Ambassador, and Opel) occurred in the fuel feed system.

The evaporative control system damage was confined to the carbon canister and/or the purge hose from the canister to the engine. The Capri purge hose from the canister to the air cleaner was pulled off at the air cleaner connection by the rearward movement of the battery. (The battery and the canister are both mounted in the front part of the engine compartment with the canister mounted underneath the battery.) The canister itself was not damaged. In the 1971 Fiat the metal fitting connecting the purge hose to the top of the canister was broken off. Although the canister in this car is mounted behind the front of the engine block, it is also mounted behind the battery. Again, as with the Capri, the rearward movement of the battery caused

TABLE 5-I. FRONT BARRIER IMPACTS - TEST DATA

Test Vehicle	Test Weight (lb)	Impact Speed (mph)	Permanent Crush Distance (in.)	Rebound Distance (in.)	Fuel System Damage	Electrical System Damage
1970 Fiat 124 Sedan	2167	29.0	13-1/2	7-1/2	No	No
1970 Fiat 124 Sedan	2110	29.0	16-1/2	16-1/2	No	No
1970 Toyota Corolla	1871	29.6	15-3/4	20-1/2	Yes	No
1970 Austin America	1968	29.4	16	14-1/2	No	Yes
1970 Chevelle Malibu	3322	29.5	23-1/4	4	Yes	Yes
1970 AMC Ambassador	3646	29.4	17	1-1/4	Yes	Yes
1971 Fiat 124 Coupe	2221	30.2	18	13	Yes	Yes
1971 Ford Pinto	2078	29.1	22	3/4	No	Yes
1971 Dodge Station Wagon	4632	29.8	28	25-1/2	No	Yes
1971 Opel Kadett Station Wagon	2058	29.4	16	2-1/2	Yes	Yes
1971 VW Squareback	2239	29.3	19-3/4	58	No	No
1971 Capri Sport Coupe	2174	29.3	21-1/2	50-3/4	Yes	Yes

the damage to the canister. The canister in the Chevelle was broken near the bottom, allowing the carbon to drop to the ground. This canister is also mounted at the front of the car, ahead of the engine block. While the Fiat and Capri canisters were made of metal, the Chevelle canister is made of plastic. It is

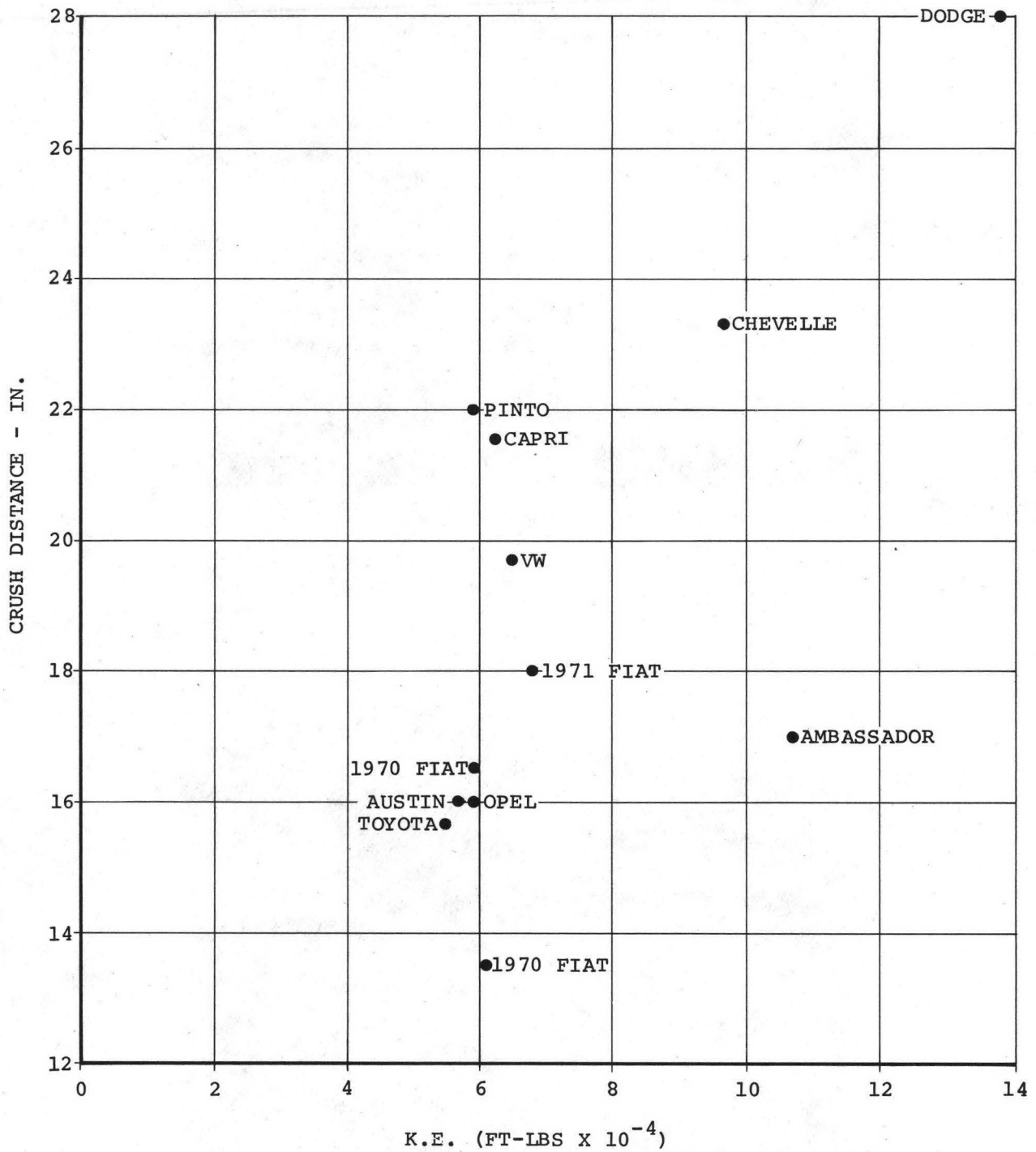


Figure 5-16. Front Barrier Impacts Permanent Crush Distance Versus Kinetic Energy.

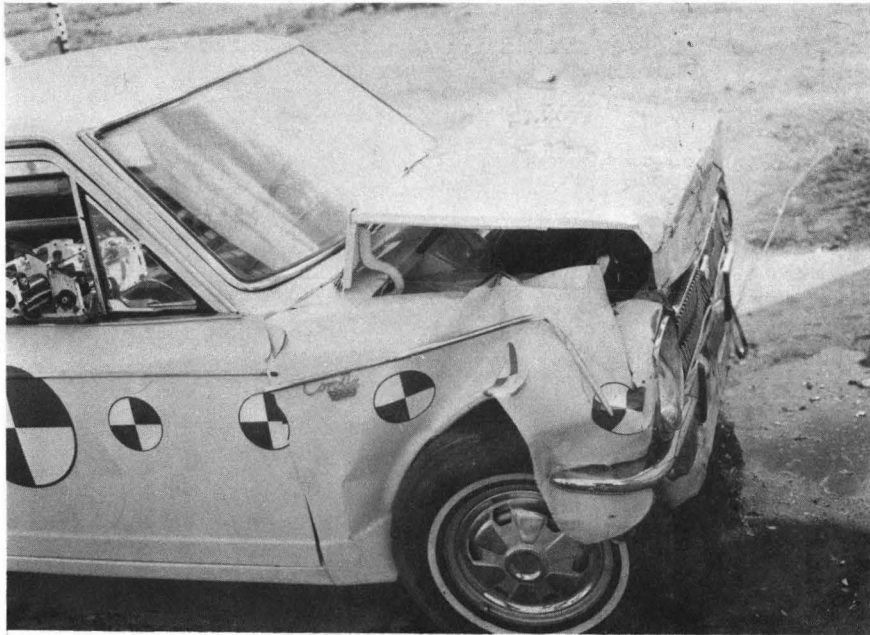


Figure 5-17. 1970 Toyota Corolla After
30-mph Barrier Test.



Figure 5-18. 1970 Chevelle Malibu After
30-mph Barrier Test.

possible that the Chevelle canister might not have broken had it also been made of metal.

Evaporative control system damage was also noted in a 1971 Pinto which was involved in a left front abutment collision which pushed the entire left side of the engine compartment back to the firewall. The circular metal bracket holding the canister in the front of the engine compartment had been almost straightened by the impact and the metal canister had been pulled from the bracket. The canister had been held in the engine compartment, however, by the vapor hose from the fuel tank and the canister itself was not damaged. However, the reinforced paper purge hose from the canister to the air cleaner had been sheared off at the canister connection.

If the canister or vapor purge hose is damaged in an accident, the small amount of free vapor in the canister or hose might be released into the engine compartment, although purging would cease when the engine stopped. The fire hazard from this released vapor would be minimal, however, because of the unlikelihood of this small amount of vapor forming a flammable fuel-air ratio. Even the spilling of the carbon contents cannot be considered a significant hazard since the fuel vapor adsorbed by the carbon is held tightly enough on the carbon surface to inhibit its escape.

Two of the three fuel feed system failures noted during the barrier tests occurred in the engine compartment (Ambassador and Toyota) while the other failure occurred in the rear of the car near the fuel tank (Opel).

The Ambassador fuel pump inlet line was broken at the pump connection. (The fuel pump is mounted on the left side of the engine near the front.) Although a small amount of leakage probably occurred at impact, there was no post-impact leakage as long as the vehicle remained upright. There was extensive leakage, however, when the vehicle was rolled over (see Section 5.3.4.2).

The Toyota carburetor was pushed back into the brake fluid reservoir, breaking both the carburetor base mounting on the intake manifold and the base of the carburetor itself, as shown in Figure 5-19. This failure graphically illustrates the hazards of fuel system component damage resulting from direct impacts on other vehicle components as the carburetor withstood the extremely high acceleration of 295G during the drop test with no damage. Again, a minor amount of fuel leakage must have occurred during impact although there was no post-test leakage. It should be noted that the intake manifold and carburetor in the 1971 Toyota Corollas are now located on the right side of the engine where there is adequate space behind the carburetor to prevent the recurrence of such a failure.



Figure 5-19. Broken Carburetor Mounting in Barrier-Crashed Toyota Corolla.

The barrier crash of the Opel resulted in fluid leakage from the fuel tank area in the right rear quarter panel immediately after impact. The initial fuel loss rate was approximately .2 ounces per minute, decreasing to zero after approximately 10 minutes. This leakage occurred from a 2-inch flexible hose segment connecting the metal fuel line from the tank to the plastic line leading to the engine compartment (see Figure 5-20). The location of the leak allowed the fuel to drip directly down onto the forward end of the muffler. Although the surface temperature of the muffler would be below the ignition temperature of gasoline, the muffler temperature would be sufficient to vaporize any gasoline on the surface, thus possibly creating a hazardous fuel-air mixture which could be ignited by an outside ignition source.

The crashed vehicle analyses indicated that vehicles involved in moderate front end collisions do not usually sustain any damage to the fuel feed system. However, a 1971 Cougar did sustain an engine compartment fire during a moderate front end

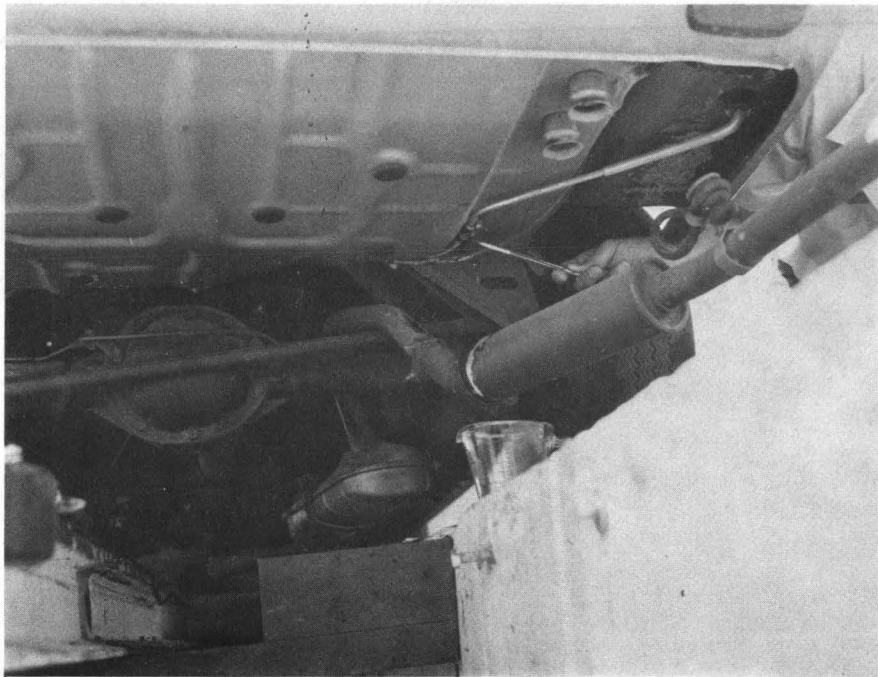


Figure 5-20. Opel Kadett Fuel Line Following Front Barrier Impact (Pencil indicates point of fuel loss).

collision. (Structural damage to the vehicle is shown in Figure 5-21). Although the plastic connector between the canister purge hose and the air cleaner was broken, no other fuel system components were damaged. Fire damage in the engine compartment was general but the most intense fire occurred on both sides of the engine block, as evidenced from the badly burned spark plug wires (see Figure 5-22). Investigators suspected that the carburetor played a major role in this fire and removed it for analysis. However, no carburetor damage could be found. The results of the analysis and the fire pattern in the engine compartment suggest that fuel surged from the carburetor during impact and was ignited either by shorted spark plug wires or by the hot exhaust manifold of the engine.

5.3.1.2.3 Electrical System Damage. Electrical system damage is common in front end impacts because of the number of electrical system components located in the engine compartment and the location of many of these components near the periphery of the vehicle. Sparks from the damaged electrical system can function as ignition sources for any fuel spilled in the engine compartment and can also function as ignition sources for fuel spilled from the struck car during a front-end-to-rear-end collision between two vehicles. The ignition hazard is especially serious if high energy components such as the battery are damaged.



Figure 5-21. 1971 Cougar Involved in a Moderate Front End Collision.

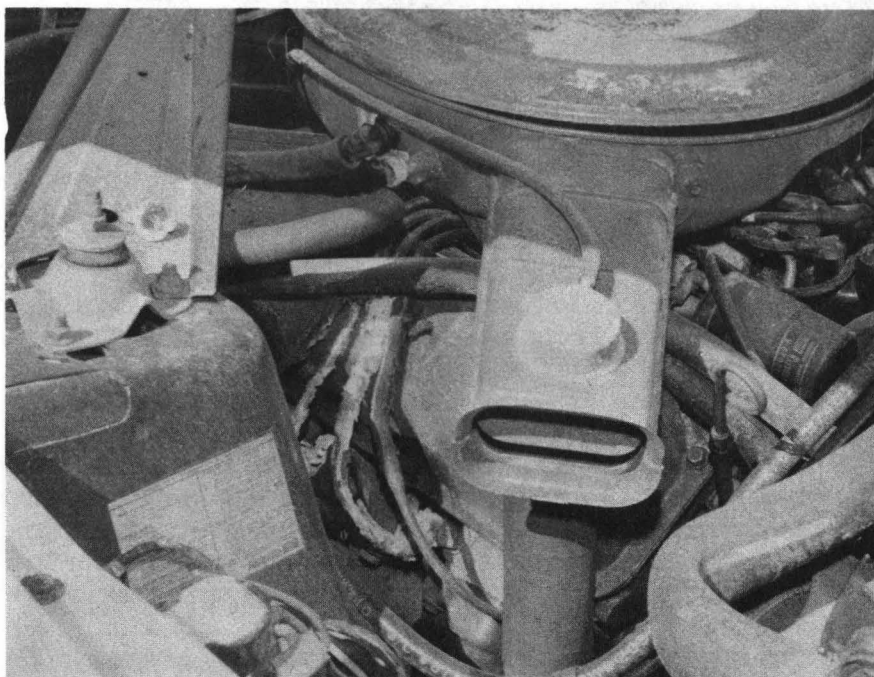


Figure 5-22. Engine Compartment Fire Damage in Crashed 1971 Cougar.

Catastrophic damage to the battery was generally experienced in those vehicles with the battery located in the front of the engine compartment when impacted into the barrier at 30 mph. Typical battery damage is illustrated in the Ambassador engine compartment shown in Figure 5-23. Sparks generated during impact as the battery is broken are potential ignition sources. The capacity of the battery to act as an ignition source may exist even when it is almost totally destroyed, e.g., although only one cell in the 1971 Fiat battery was not destroyed, the passenger compartment light functioned when the doors were opened after the impact. Thus, destruction of the battery does not eliminate it as an ignition source.

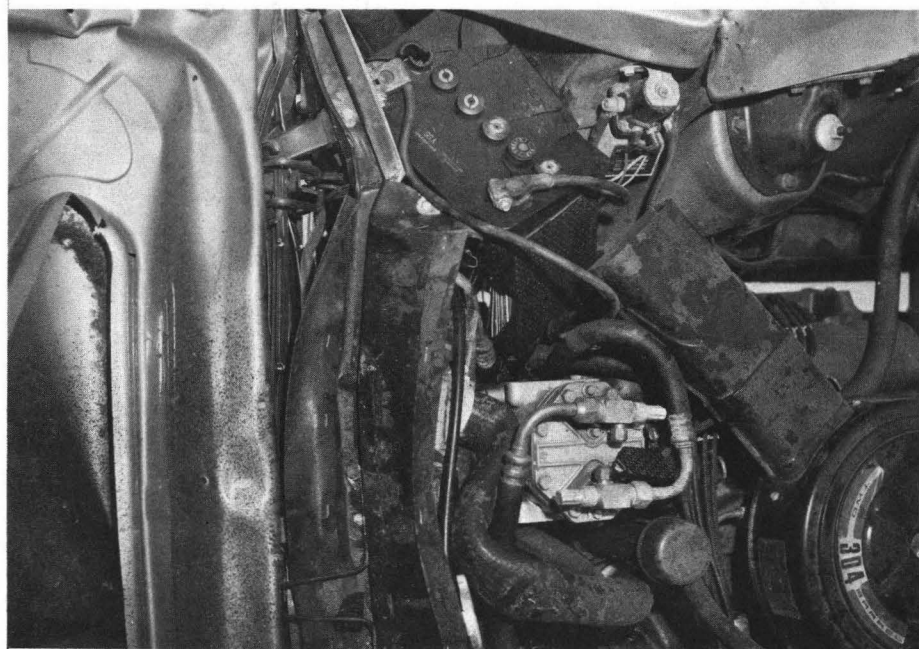


Figure 5-23. Battery Damage in Barrier-Tested Ambassador.

The battery in the Capri, which was also front barrier impacted, sustained another type of damage. Although the battery was not smashed as in the Ambassador, the battery was pushed back into the power brake reservoir which penetrated the battery case (see Figure 5-24). Previous test experience has shown that considerable sparking can occur when the battery case is penetrated by an object.

One notable exception to battery damage was noted in the Dodge station wagon. Although this battery was located in the extreme front of the engine compartment, the only damage it sustained was the loosening of the positive pole inside the case.

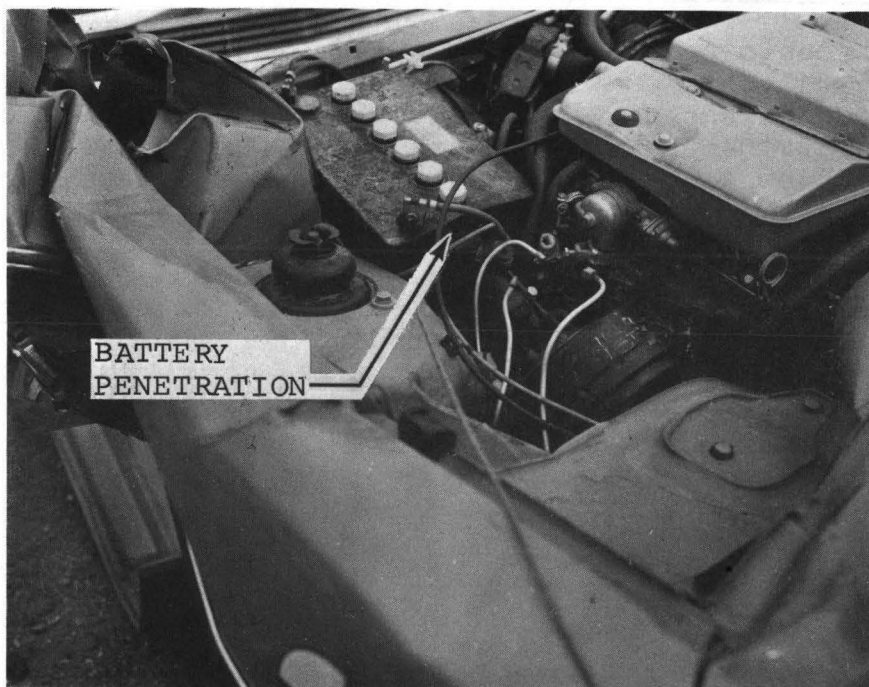


Figure 5-24. Battery Damage in Barrier-Tested Capri.

The case itself remained intact. The damage was minimized because the battery was adequately clamped to the vehicle structure and moved rearward into an open area as the front of the vehicle was pushed back.

Severe battery damage during front impact tests was not confined just to batteries located in the extreme front part of the engine compartment. Figure 5-25 shows the damage sustained by the Pinto battery which is located on the right splash guard midway back in the engine compartment. The battery was originally oriented so that both of the battery terminals were near the fender. The plastic clamp that holds the battery in place was broken during the impact, allowing the battery to rotate 90 degrees. Impact damage may be seen on what was originally the front end of the battery. This damage undoubtedly came from deforming front end structure during the impact.

Battery damage was also sustained by the Opel which contains the battery in the rear of the engine compartment near the firewall. The battery is clamped to the structure by two metal rods which slip through mounting bracket holes on the underfloor structure at the rear of the engine compartment. Structural deformation in the bracket area allowed the rods to slip free and the battery was torn completely loose during the impact. Both battery cables were pulled off the terminals and the case was broken on the right side. It is possible that this battery would not have sustained damage had its attachment to the structure been more secure.

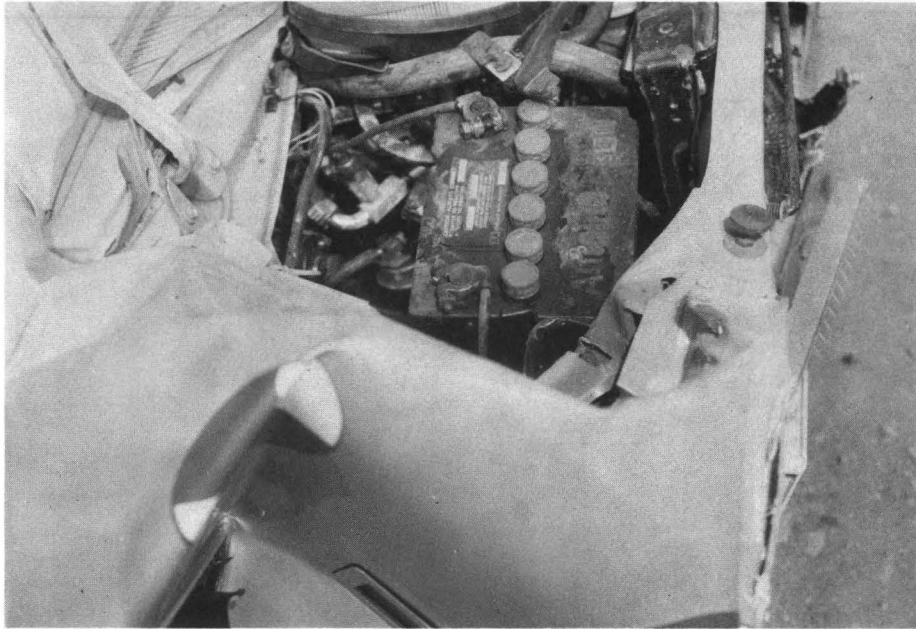


Figure 5-25. Battery Damage in Barrier-Crashed Pinto.

Sparking can occur from the battery even though it is not damaged if sheet metal structure comes in contact with the positive battery terminal. One such instance was found during the crashed vehicle analyses in a Ford Pinto which suffered a relatively minor impact to the right front end of the vehicle. The plastic clamp which holds the battery in place was broken, allowing the battery to move so that the positive terminal came in contact with the right front fender well (see Figure 5-26).

5.3.1.2.4 Exhaust System Damage. There was no exhaust system damage evident in any of the vehicles which were involved in front end collisions.

5.3.1.3 Non-Crashed Vehicle Analyses

5.3.1.3.1 Fuel System. Most of the fuel system hazards uncovered during the non-crashed vehicle analyses were also observed in the crashed vehicles and have been discussed above under impact damage. These include the damage that may be expected to the carbon canisters, vapor lines, and fuel lines located in the front part of the engine compartment. However, there are two additional hazards uncovered during the new vehicle analyses that warrant discussion here.

All of the fuel pumps in the vehicles analyzed, with the exception of the Plymouth Cricket, are fairly resistant to impact damage because they are small, generally located on the side of the engine block away from the periphery of the vehicle, and made

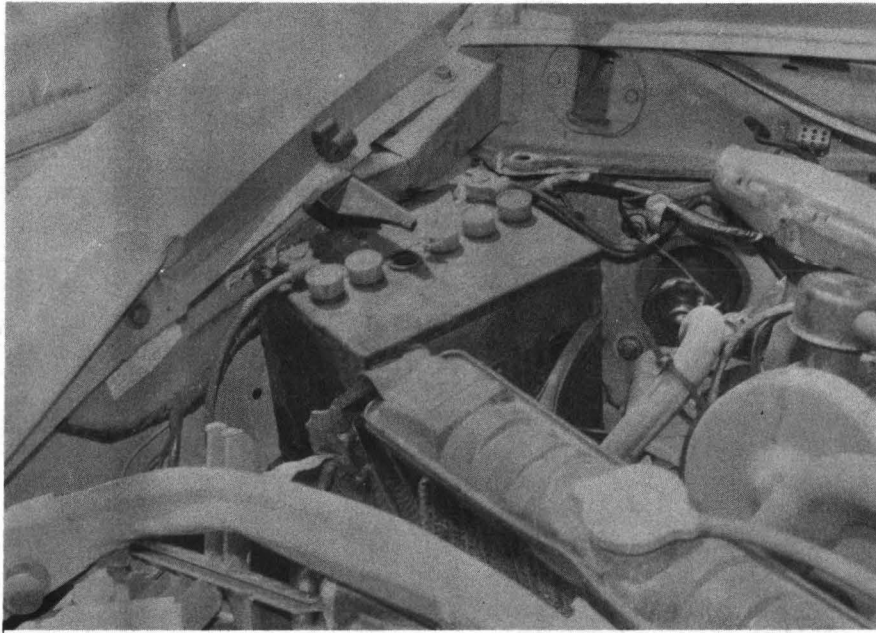


Figure 5-26. Displaced Battery in Pinto Involved in Minor Front End Collision.

entirely of metal. The Cricket fuel pump, however, contains a glass cover bowl which could be broken during a front end impact. Although the amount of fuel contained in the pump is small, the possibility of fuel ignition does exist. An even greater hazard would result from the broken fuel pump bowl during a roll-over accident as large quantities of fuel from the fuel tank could be spilled through the broken pump.

A definite fire hazard could exist under some conditions in those Toyota sedans which contain the vapor storage tank in the front of the engine compartment (see Sections 4.7.1 and 4.7.2). If the vehicle has been in operation for some time, the vapor tank will be purged of most vapor and only a minimal hazard would exist during a front end impact which damaged the vapor tank. However, complete purging of the tank would take some time and, if the vehicle had just been started after a soak period, the storage tank could be full of fuel vapor. Its location in the front of the engine compartment makes it particularly susceptible to impact damage and, should the tank be ruptured, a considerable amount of fuel vapor could be dispersed in the engine compartment. Although the battery is located on the opposite side of the engine compartment, it is in the extreme front and any impact sufficient to damage the vapor storage tank could well damage the battery also. Should the vapor be ignited, a catastrophic fire would result.

Those vehicles which contain the fuel tank in the front of the car would seem to present a severe hazard because of the fuel tank's susceptibility to crash damage during a front end collision. However, the vehicles which are sold now must pass FMVSS 301 which specifies no fuel tank, filler neck, or fuel tank attachment failures during a front barrier impact at 30 mph. Thus, one must assume that these vehicles are safe up to this speed, as the barrier impact of the Volkswagen Squareback already mentioned would indicate. Front end impacts above this speed, however, could well result in failure of the fuel tank with attendant massive fuel spillage.

5.3.1.3.2 Electrical System. Electrical system hazards uncovered during the non-crashed vehicle analyses were identical to those found in the crashed vehicles. The battery must again be considered the most hazardous component since it is almost universal practice to locate the battery in the forward part of the engine compartment. The battery itself does not have to be damaged to function as an ignition source. If the positive battery terminal comes in contact with sheet metal structure or some other grounded part of the vehicle, sparking can occur. This situation is even more probable in those vehicles using batteries with side terminals, as in some 1970 and most 1971 Chevrolets.

5.3.2 Rear Impacts. The determination of fire hazards resulting from rear end impacts was based on data obtained from sled tests, rear impact barrier tests, and actual automobile accidents. The sled tests were used to assess the integrity of the fuel systems to impact accelerations only, while the barrier tests and automobile accidents furnished information on damage due to vehicle structural deformation and direct impacts upon fuel system components. The results of these tests were then extrapolated to analyze the susceptibility of non-crashed vehicle systems to rear impact damage.

5.3.2.1 Acceleration Damage. Sled tests (which are described fully in Appendix F) were conducted on 1970 Ford, General Motors, and Toyota fuel system components and subsystems. The complete subsystems were tested at velocities of 30 mph and selected components were tested at 45 mph. The accelerations ranged from 38 to 57G.

The only component damaged was the Chevelle fuel tank which was distorted by the fluid surge within the tank. This fluid surge bulged the tank bottom at the rear of the tank and pulled the center forward bottom of the tank inward. Although leakage occurred around the tank accelerometer mounting, which was located in the distorted area, no leakage would have occurred in the absence of the accelerometer. The fuel tank did shift approximately 1 inch in the direction of impact, but the holding straps restrained the tank and no damage occurred from the movement.

A small amount of fluid leaked around the filler cap of the Mustang and the Chevelle during these tests. Although the amount of fluid lost was small, it must be considered a definite fire hazard during a rear end impact as the many ignition sources located in the engine compartment of the striking vehicle would be in close proximity to the fuel lost from the filler cap of the struck vehicle. This is especially hazardous if the fuel is in the form of a spray which could exist in a highly flammable fuel-air mixture. If the fuel were ignited, flames could quickly spread to the fuel tank of the struck vehicle.

5.3.2.2 Impact Damage

5.3.2.2.1 Structural Damage. A quantitative assessment of the structural damage that can be expected at various speeds during rear end collisions was obtained from five rear barrier impact tests conducted during this program. All of these vehicles had been previously subjected to front barrier impacts and, although some minor modifications to the front structures of the vehicles were necessary to allow them to track into the barrier, the rear structures of the vehicles were undamaged and thus offered valid test specimens. Accelerometers were installed in the vehicles to measure impact accelerations and barrier load cells were used to measure impact forces. A detailed description of the test methodology and results is presented in Appendix G. A brief summary of the results is presented below.

Basic test data are presented in Table 5-II. Table 5-II also shows the wide variety of vehicles that were tested. The vehicles consisted of two sub-compacts (Toyota Corolla and Ford Pinto), one station wagon (Dodge), and two standard size passenger cars (Chevelle Malibu and AMC Ambassador). The fuel system configurations also varied widely. They consisted of one rear tank with rear filler (Chevelle), two rear tanks with side fillers (Ambassador and Pinto), one fender tank (Dodge station wagon), and one mid-tank mounted above the rear axle behind the rear seat (Toyota).

Dynamic and permanent crush distances are also shown in Table 5-II. The majority of the crushing occurred behind the rear axle in all of the vehicles except the station wagon, as may be seen in Figures 5-27 through 5-30. The station wagon rear frame buckled upward extensively above and immediately forward of the rear axle, thus allowing the whole rear body structure to move forward, as shown in Figure 5-31. The passenger compartment was buckled in the rear seat back area as shown in Figure 5-32.

A plot of the vehicle crush distance versus kinetic energy is shown in Figure 5-33. Unlike the front barrier impact, the rear barrier impacts show a good correlation of crush distance with kinetic energy with the exception of the Dodge station wagon.

TABLE 5-II. REAR BARRIER IMPACTS - BASIC TEST DATA						
Vehicle	Test Weight (lb)	Impact Speed (mph)	Dynamic Crush Distance (in.)	Permanent Crush Distance (in.)	Rebound Distance (in.)	
1970 Toyota Corolla	2,345	30.2	32-1/4	24-1/4	39-3/4	
1971 Dodge Station Wagon	5,795	27.6	24-3/4	20-1/2	5	
1970 Chevelle Malibu	4,176	21.8	27-1/2	23-1/2	5-1/2	
1970 AMC Ambassador	4,530	20.2	25-1/2	20-3/4	3	
1971 Ford Pinto	2,685	20.1	18-1/2	13	17-1/4	



Figure 5-27. Toyota Impact Damage From 30.2-mph Barrier Test.

Since, however, the number of data points is limited, the correlation should not be used indiscriminately for all types of vehicles.

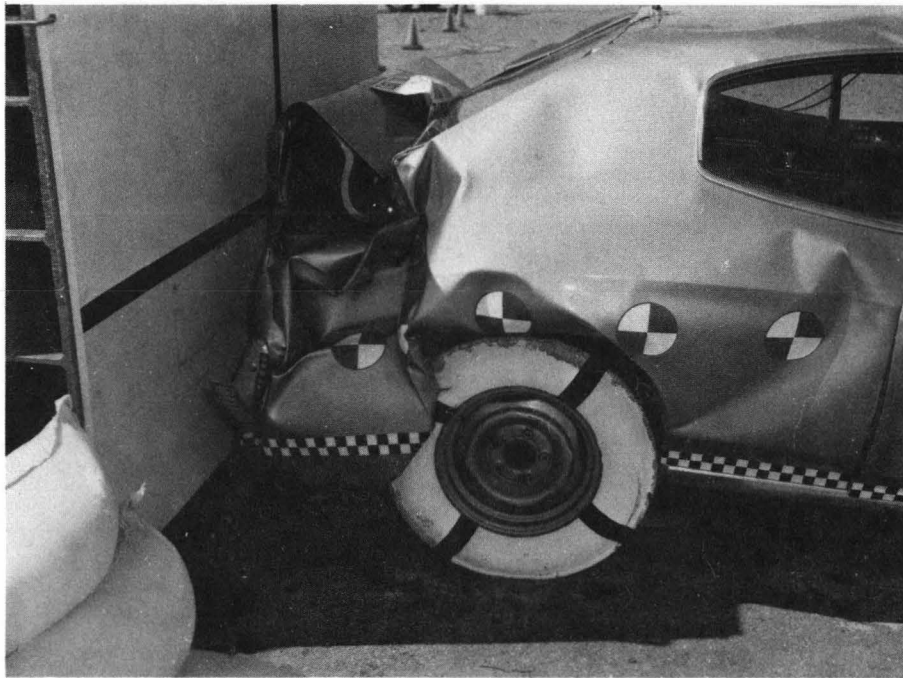


Figure 5-28. Chevelle Impact Damage From 21.8-mph Barrier Test.



Figure 5-29. Ambassador Impact Damage From 20.2-mph Barrier Test.



Figure 5-30. Pinto Impact Damage From 20.1-mph Barrier Test.



Figure 5-31. Dodge Station Wagon Impact Damage From 27.6-mph Barrier Test.

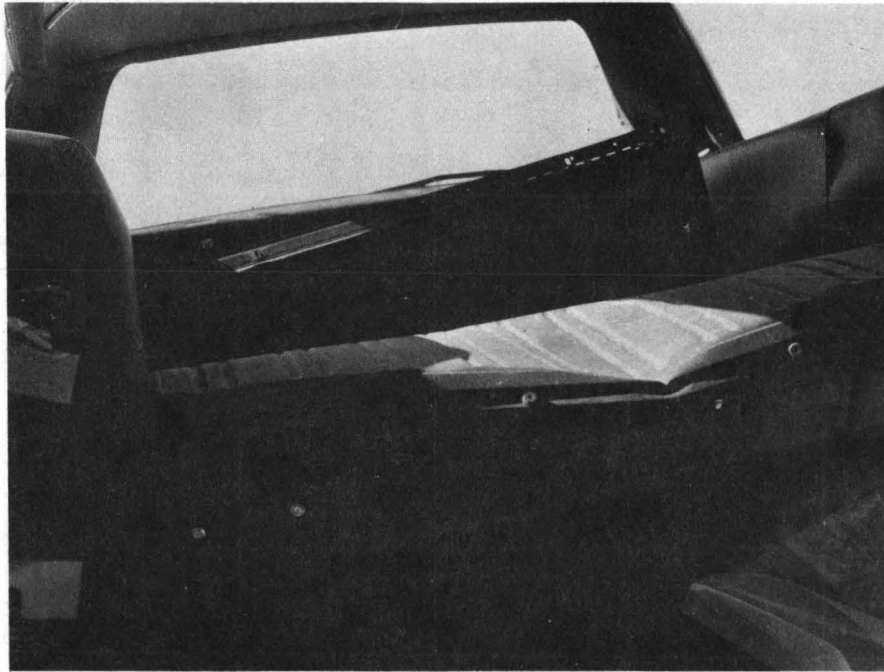


Figure 5-32. Interior Damage in Rear of Dodge Station Wagon.

The peak accelerations obtained during the tests are shown in Table 5-III. (All data traces are contained in Appendix G.) Unfortunately, a malfunction of the magnetic tape recorder precluded the acquisition of data from the accelerometers and barrier load cells during the Toyota test.

The peak longitudinal accelerations in the occupant compartment and on the engine and frame in all the vehicles ranged between 10 and 20G. The Dodge accelerations were all near the upper end of the range due to the higher impact speed and the body style of the vehicle. Frame accelerations of the Chevelle were oscillatory with peaks as high as 26G. The peak accelerations in the fuel tank area were all greater than those on the frame with the exception of the Chevelle, which were in the same range. This is probably to be expected since all of the fuel tank area accelerometers were located behind the rear axle so that they had less crush distance than the frame accelerometers. The Dodge fuel tank acts to stiffen the body in the tank area. This is evidenced by less crushing behind the rear axle on the left side than on the right side and by the high acceleration recorded in the fuel tank area.

The results of kinematic analyses of the high-speed test films are shown in Figures 5-34 through 5-38. The crushing rate in the Toyota was nearly linear until very close to the maximum

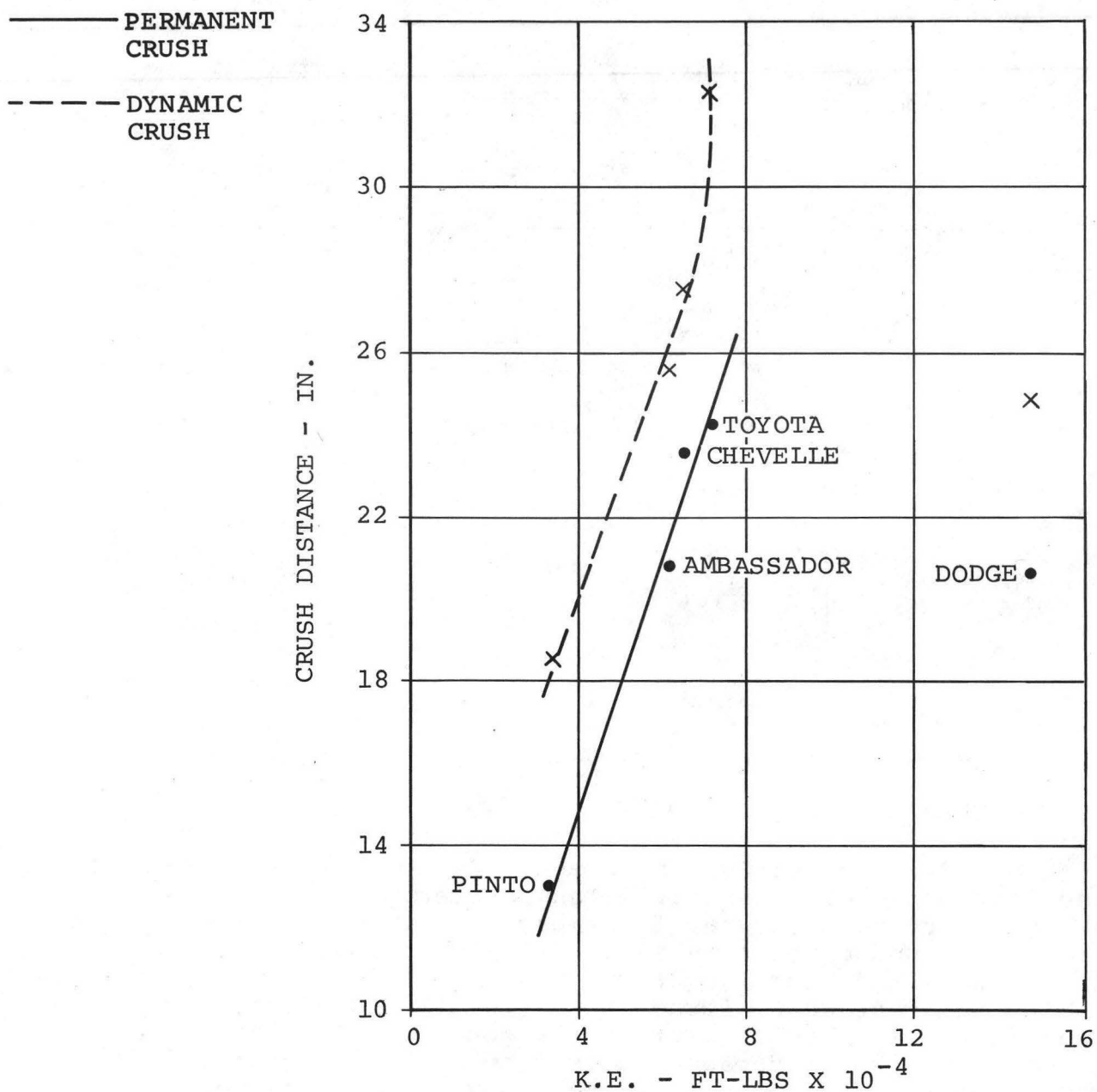


Figure 5-33. Rear Barrier Impacts Crush Distance Versus Kinetic Energy.

dynamic crush, as may be seen from the initial slope of the curve in Figure 5-34. All of the other vehicles exhibited a decrease in the crushing rate after the time at which maximum barrier force was recorded. Although barrier force data for the Toyota were not obtained, maximum force could probably be assumed at no later than 30 msec.

TABLE 5-III. PEAK ACCELERATIONS - REAR IMPACT BARRIER TESTS									
Accelerometer Location	Direction of Measurement	Dodge Station Wagon		Chevelle		Ambassador		Pinto	
		Positive (G)	Negative (G)	Positive (G)	Negative (G)	Positive (G)	Negative (G)	Positive (G)	Negative (G)
Occupant Compartment (Center, on Tunnel)	Vertical	21	19	7	6	15	8	15	13
Occupant Compartment (Center, on Tunnel)	Longitudinal	20	0	11	0	11	4	17	3
Occupant Compartment (Center, on Tunnel)	Lateral	Insignificant		Insignificant		Insignificant		28	19
Engine	Vertical	13	17	Insignificant		6	7	6	13
Engine	Longitudinal	26	6	25	8	21	3	20	4
Engine	Lateral	Insignificant		Insignificant		Insignificant		Insignificant	
Left Frame (Under "B" Pillar)	Vertical	9	6	5	11	6	7	10	8
Left Frame (Under "B" Pillar)	Longitudinal	19	0	20	7	9	0	16	0
Right Frame (Under "B" Pillar)	Longitudinal	19	0	26	11	11	0	16	0
Fuel Tank Area	Vertical	19	10	23	17	23	6	25	15
Fuel Tank Area	Longitudinal	53	8	22	8	22	0	35	6

5.3.2.2.2 Fuel System Damage. As noted in the previous section, three different fuel tank/system configurations were subjected to the rear barrier impact test. These were: (1) rear tank slung under the body structure (found in the Chevelle, Ambassador, and Pinto), (2) mid-tank located above the rear axle behind the rear seat (found in the Toyota), and (3) rear fender tank (found in the Dodge station wagon). It is worthwhile to discuss the impact damage incurred by each configuration separately as the damage and failure modes varied considerably between the different configurations.

As expected, all of the rear underfloor tanks suffered extensive damage during the barrier tests. All of the tanks were crushed between the rear of the vehicle structure and the differential gear housing as shown in Figure 5-39. The high-speed test film showed that the differential hit the fuel tank between 33 and 42 msec after impact. Maximum penetration of the fuel tank by the differential housing and maximum dynamic crush of the vehicle occurred simultaneously. The fuel tanks were flexible and withstood well the physical crushing and hydraulic forces of the test fluid within the tank. The resilience of the tanks may be seen by comparing the dynamic crush of the tanks

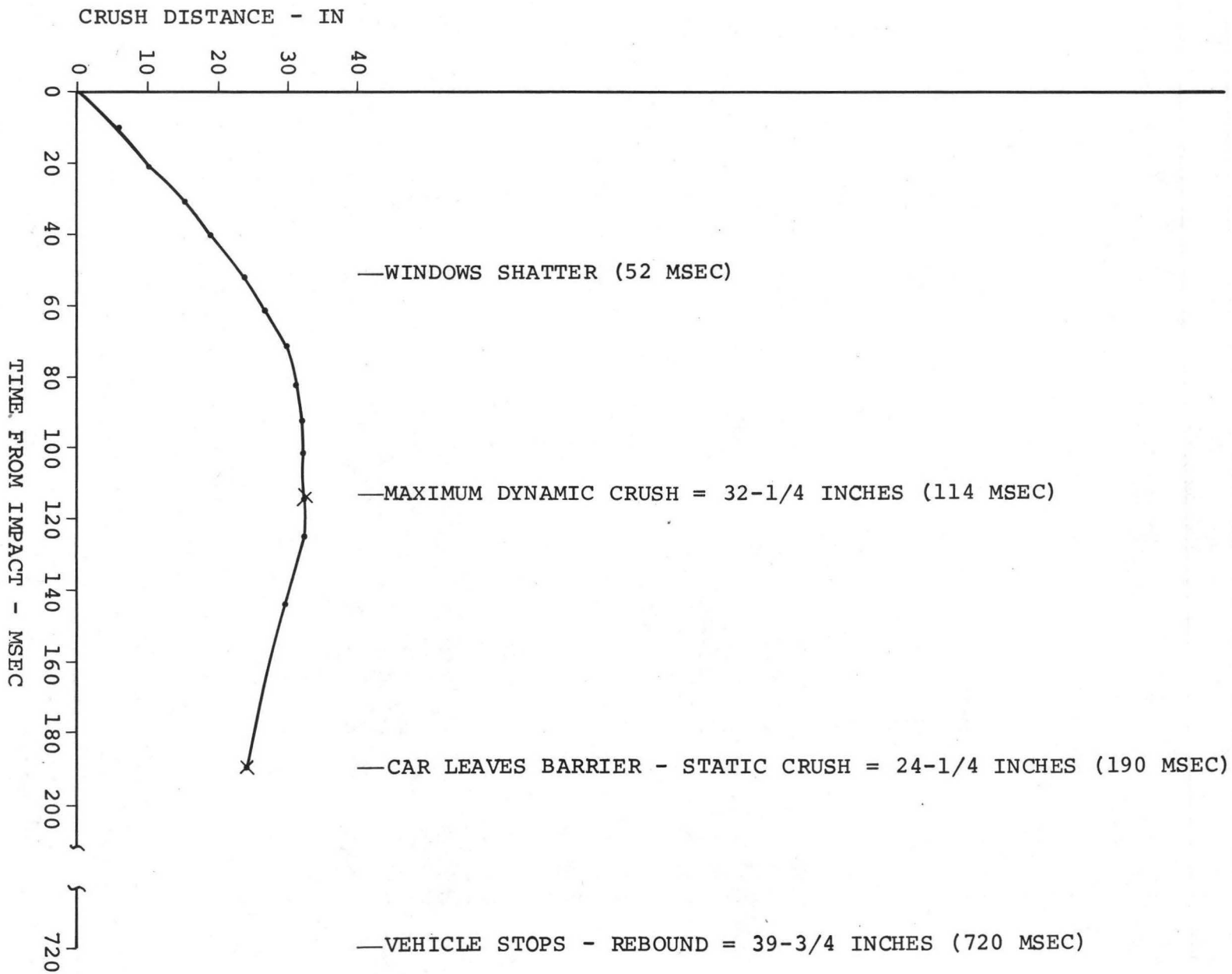


Figure 5-34. Chronology of Crash Events -
1970 Toyota Corolla.

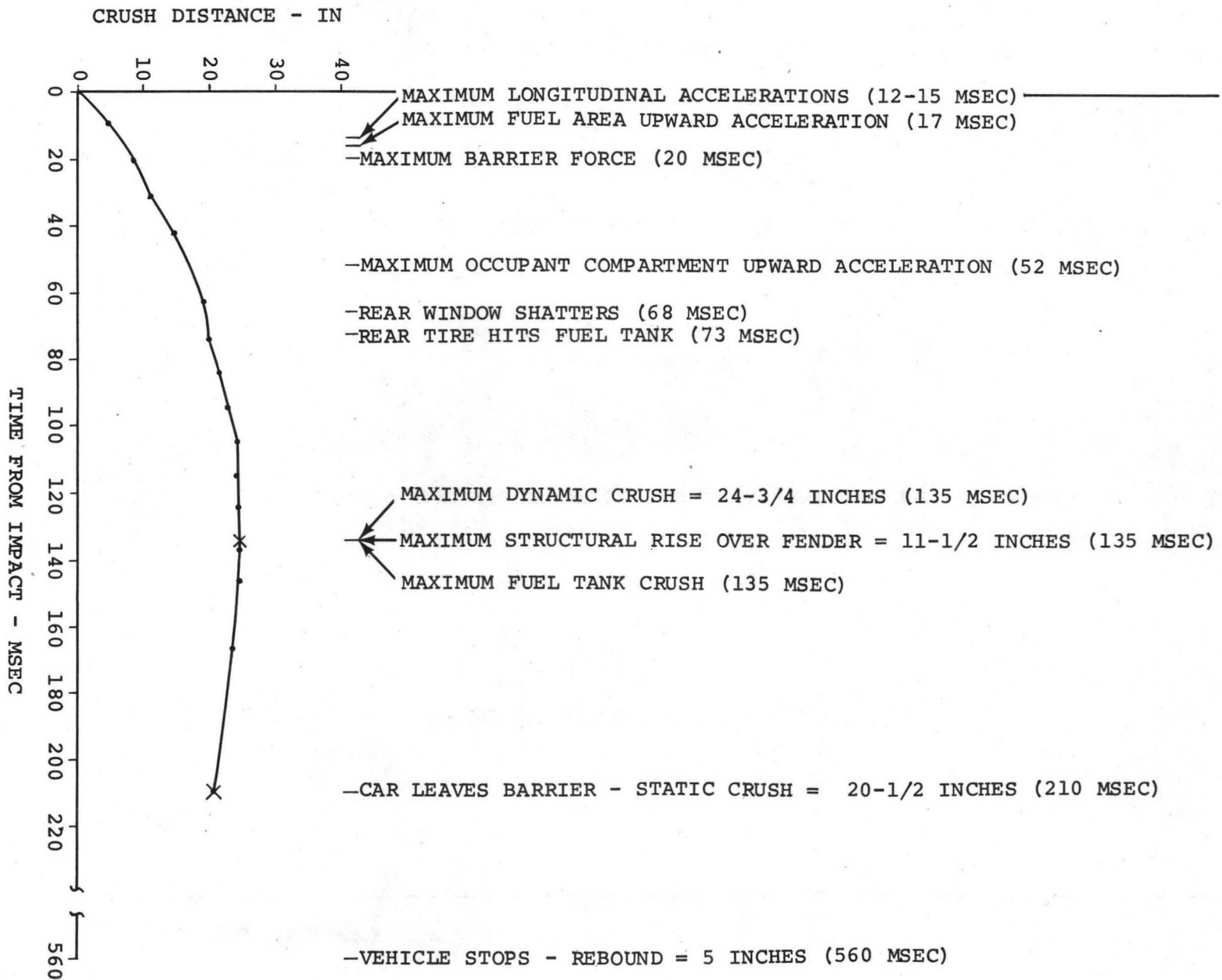
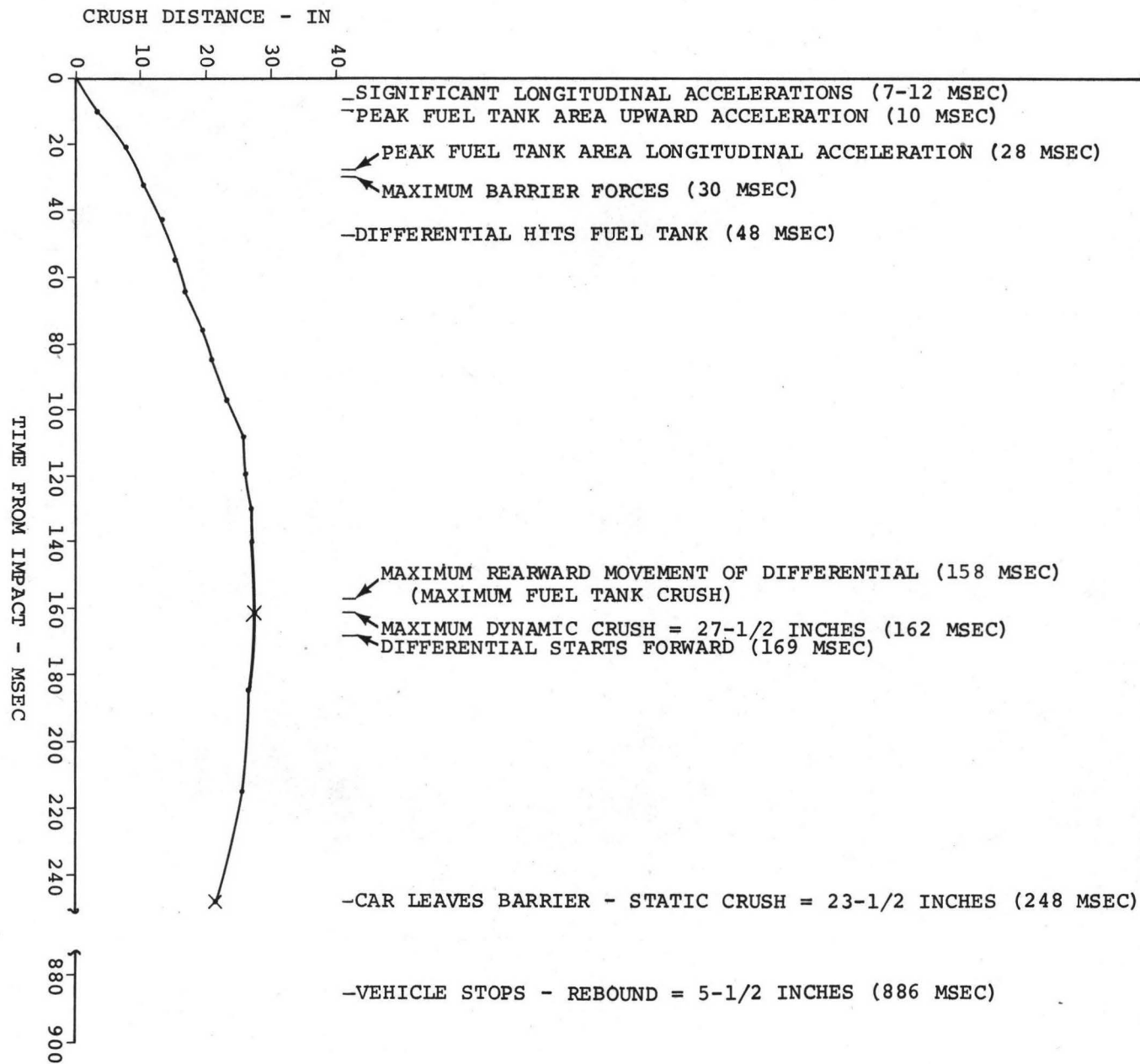


Figure 5-35. Chronology of Crash Events - 1971 Dodge Station Wagon.

with the static crush (Table 5-IV). Although leakage did occur in the Chevelle and Pinto systems, none of the failures were due to splitting of the tank metal or the welded tank seams.

Figure 5-36. Chronology of Crash Events - 1970 Chevelle Malibu.



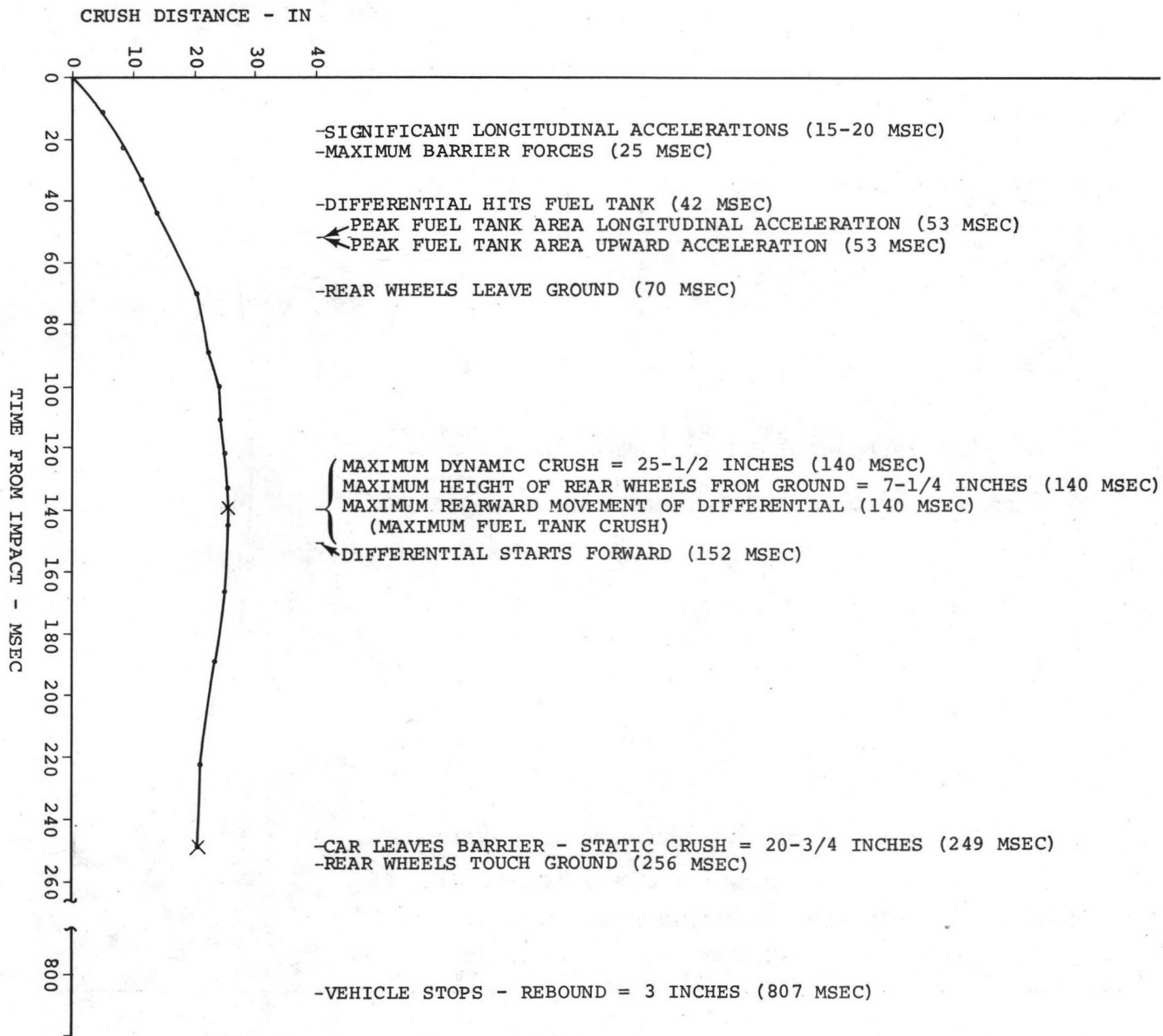
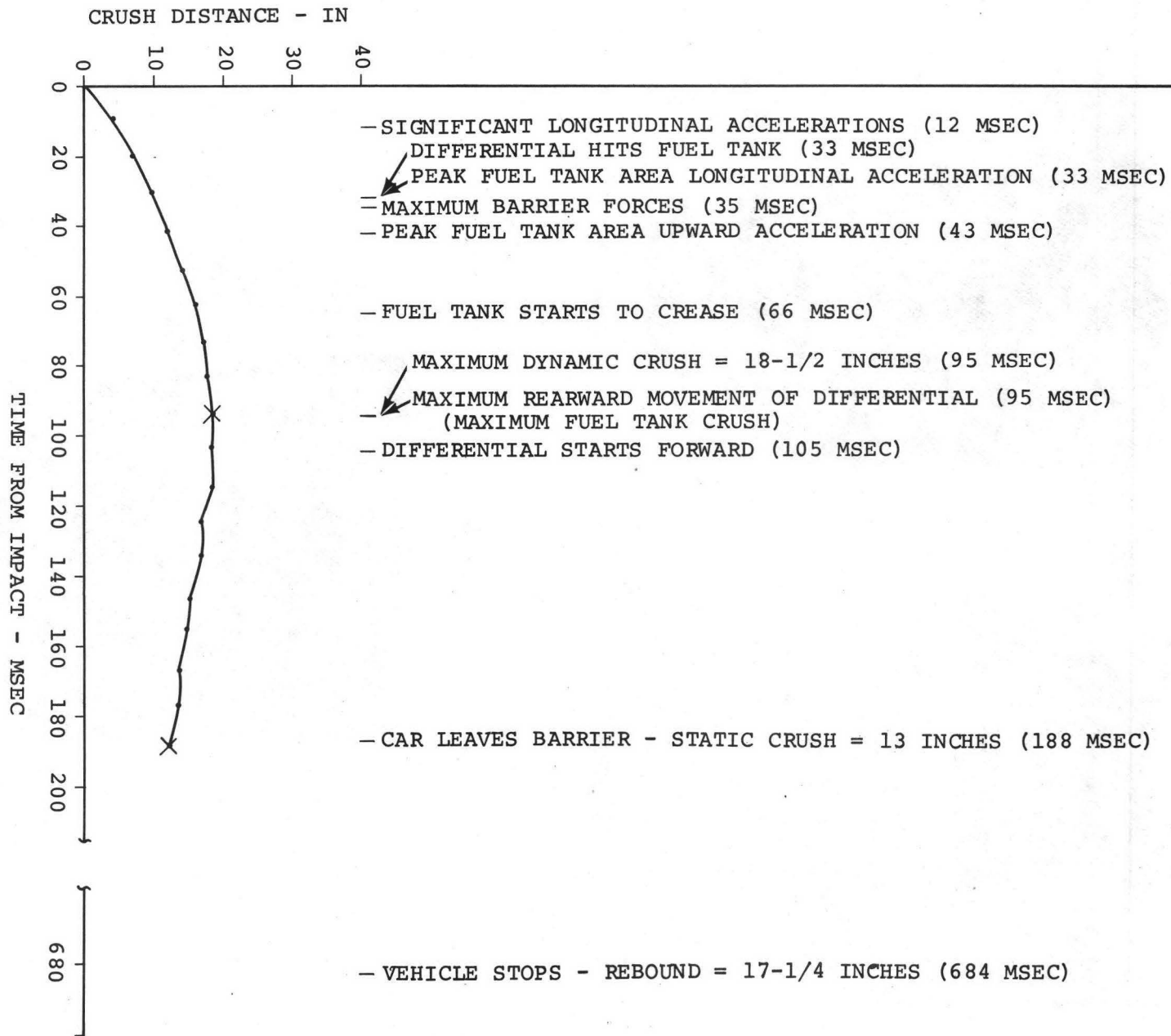


Figure 5-37. Chronology of Crash Events -
1970 AMC Ambassador.

Post-test fuel spillage from the Chevelle averaged 2.2 ounces per minute between the second and fifth minute after impact. This spillage occurred at the filler pipe-fuel tank connection. During impact, the rear filler pipe was trapped

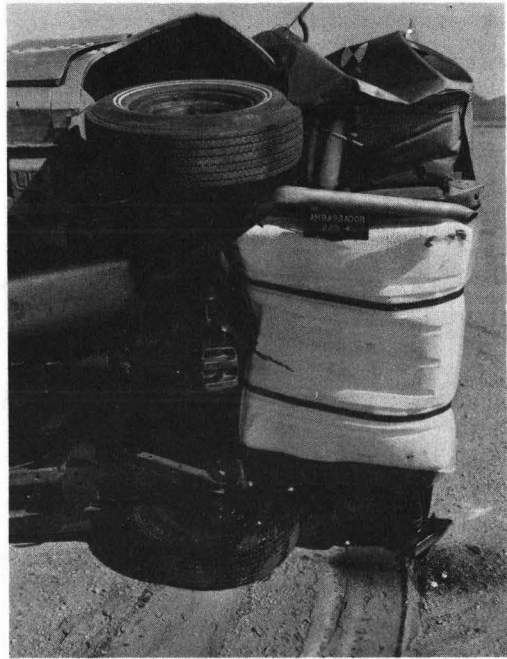
between the rear frame cross member (which moved up as the frame buckled) and the trunk floor pan, crushing the pipe and partially pulling it from the soldered connection in the tank.

Figure 5-38. Chronology of Crash Events - 1971 Ford Pinto.

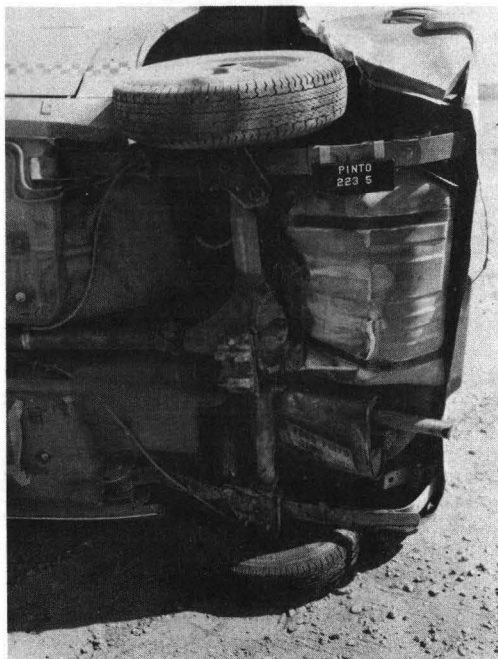




CHEVELLE



AMBASSADOR



PINTO

Figure 5-39. Fuel Tank Damage Caused by Rear End Barrier Impacts.

TABLE 5-IV. FUEL TANK CRUSHING SUSTAINED DURING
REAR BARRIER TESTS

Vehicle	Dynamic Crush Distance (in.)	Permanent Crush Distance (in.)
1970 Chevelle Malibu	6-1/2	5
1970 AMC Ambassador	4	3
1971 Ford Pinto	4-1/2	3

Although the fuel tank was badly deformed, the only spillage occurred at the filler pipe connection.

It is instructive to compare the damage to the Chevelle fuel tank with that sustained by the Ambassador tank. The vehicle structural crushing and the fuel tank crushing were very similar. However, no fuel spillage occurred in the Ambassador. The Ambassador tank is filled from the side through a filler located in the left rear fender. Although the tank moved forward approximately 1-1/2 inches in relation to the filler cap, the filler neck was undamaged. There was no damage to the filler pipe or the filler pipe tank connection in the Pinto either, which also fills from the side. The results of these three tests illustrate the hazard present with a rear tank filler during a rear impact. This hazard is reduced when the rear tank is equipped with a side filler.

The failure of the rear filler pipe at the fuel tank connection is a common occurrence and is not confined to severe accidents. Figure 5-40 shows the damage sustained by a 1970 Chevelle from a moderate left rear impact. The filler pipe was pulled from the soldered fuel tank connection, as shown in Figure 5-41, in the same manner as occurred during the Chevelle barrier test although the impact damage to the vehicle was much less. Even a relatively minor rear end collision, if it occurs in the filler pipe region, may cause failure of the filler pipe to the tank connection, as it did in the 1970 Torino shown in Figure 5-42.

Another mode of fuel tank failure during rear end collisions was illustrated during the barrier test of the Pinto. During impact, the right front part of the fuel tank was struck by the differential housing, puncturing two holes in the tank (see Figure 5-43) which resulted in a spillage rate of 18 ounces per minute. One hole was caused by a nut on the differential housing and the other by the edge of the housing adjacent to the nut. The imprint of the nut is clearly visible in Figure 5-43. The high-speed test film showed that the differential first struck the tank in the right front center and then rotated upward into



Figure 5-40. Rear End Collision Damage to 1970 Chevelle.

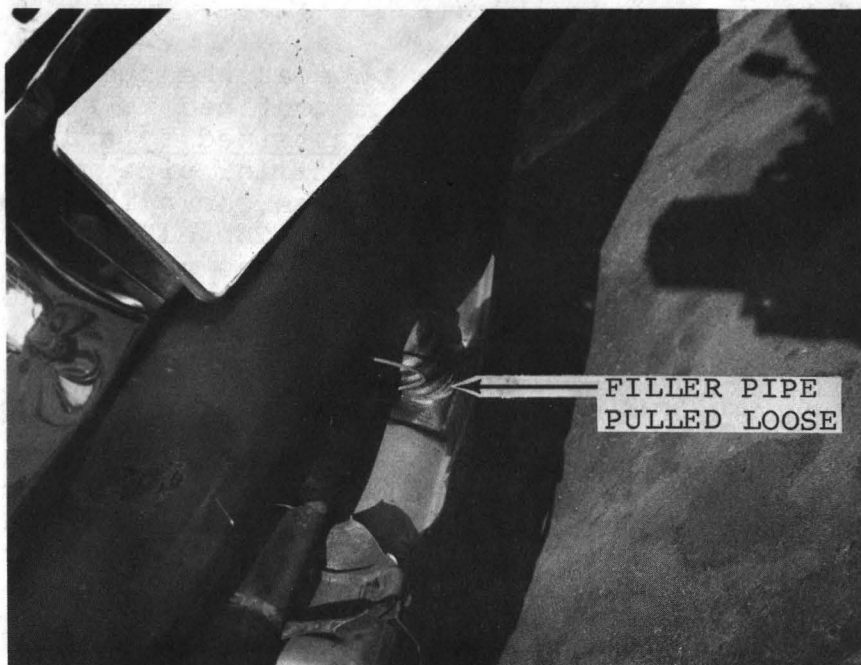


Figure 5-41. Filler-Tank Failure in Moderate Rear End Collision.



Figure 5-42. Rear End Collision Damage to 1970 Ford Torino.

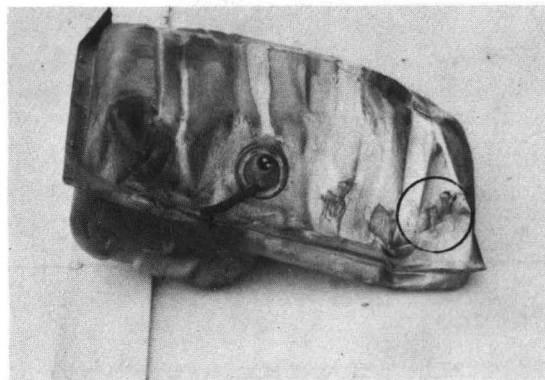


Figure 5-43. Punctures in Barrier Crashed Pinto Fuel Tank.

the tank as vehicle crushing continued, puncturing the tank at maximum crush and rotation. The asymmetrical position of the fuel tank with respect to the differential housing (see view of Pinto in Figure 5-39) probably contributed to the failure by allowing the tank to wrap around the edge of the housing. Although the fuel tank in the Chevelle and Ambassador were also struck by the differential housing, the symmetrical position of the tanks with respect to the differentials prevented the tanks from wrapping around the edge of the housings and the tanks were not punctured. However, even in this symmetrical position, a severe rear end collision can result in puncture by the differential as in the case of the Chevelle Malibu shown in Figure 5-44. Two tears in the front of the fuel tank, one approximately 6 inches long and the other 2 inches long (see Figure 5-45) resulted when the tank was pushed against the differential housing. A failure of this type can lead to very rapid loss of a large quantity of fuel which, if ignited, would result in a catastrophic fire.



Figure 5-44. Severe Rear End Collision Damage in 1971 Chevelle Malibu.

Another type of fuel tank failure which can occur during a rear end collision is the puncturing of the fuel tank by the structure of the striking car, as shown in Figure 5-46. This tear, which also occurred in the Malibu discussed above, measured

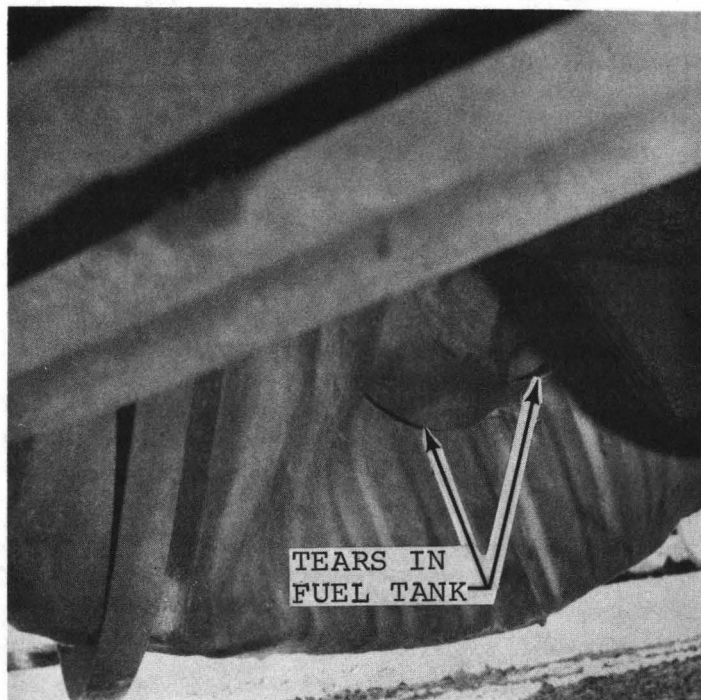


Figure 5-45. Fuel Tank Damage Caused by Differential Housing During Severe Rear End Collision.

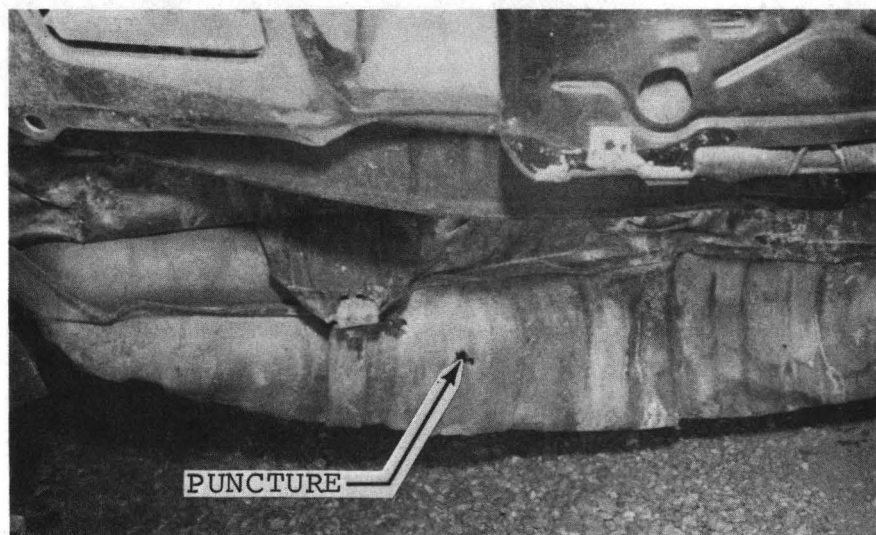


Figure 5-46. Fuel Tank Puncture Caused by Striking Vehicle During Severe Rear End Collision.

approximately 1-inch x 1-1/2 inches. Again, failure of this type would lead to rapid loss of fuel. It should be noted that in this particular vehicle both side frame rails were buckled and the doors were jammed. If a fire had started, the chances for occupant escape would have been very slim.

The mid-tank in the barrier-tested Toyota, due to its forward location above the rear axle, was not directly impacted during the test although the dynamic crush of the vehicle measured 32 inches. The post-test view in Figure 5-47 shows the fuel tank relative to the crushed vehicle structure.



Figure 5-47. Toyota Fuel Tank Following 30-mph Barrier Test.

Although there was no post-impact fuel spillage from the Toyota, examination of the vehicle disclosed that approximately 0.3 ounce of fuel surged through a broken filler neck-fuel tank vapor line connection on top of the fuel tank (see Figure 5-48). This soldered connection had been broken by the impact of the vapor storage tank which is located above the fuel tank and protrudes behind the fuel tank several inches. The deformation of the Toyota structure also pulled the tank fuel feed hose from the metal fuel line leading to the engine compartment, as may be seen in Figure 5-48. Although no fuel spillage occurred from the separated line either on or after impact, the entire fuel tank

contents were spilled through the broken line when the vehicle was rolled on its right side (see Section 5.3.4.2). It should be noted that the hose was held onto the metal pipe by means of one small spring type clamp, which may be seen still attached to the hose in Figure 5-48. Obviously, this type of clamp is insufficient to withstand any pulling forces on a hose.

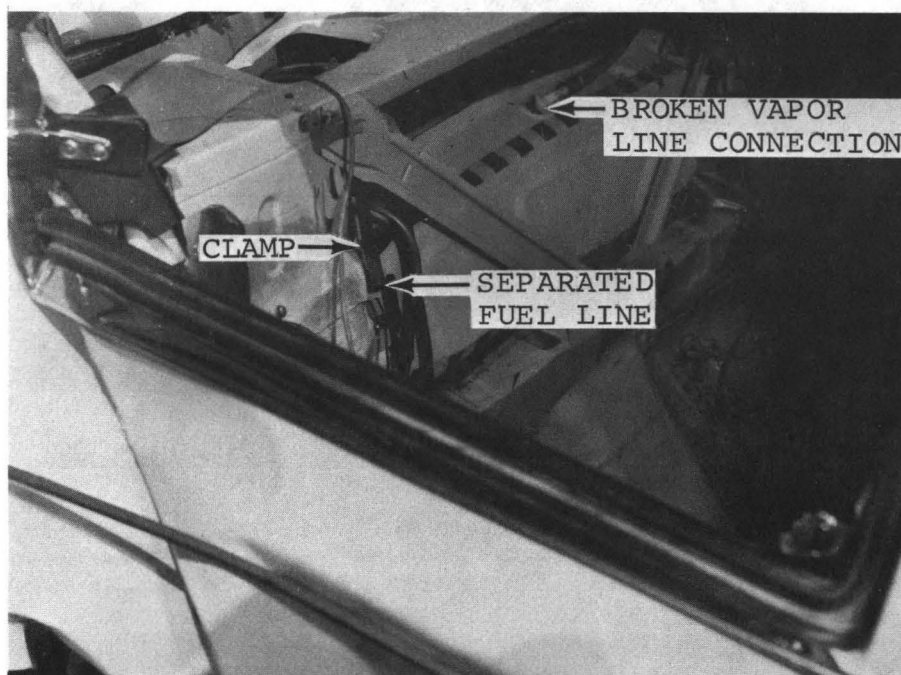


Figure 5-48. Broken Fuel and Vapor Lines in Barrier-Tested Toyota.

Although the fuel tank in the barrier crashed Dodge station wagon was severely distorted and crushed as shown in Figure 5-49, no failure occurred in the tank. The fuel tank was compressed between the rear structure of the vehicle and the left rear tire during impact, but fortunately there were no structural protrusions near the tank which could puncture it.

Although the Dodge fuel tank was not damaged, a fuel surge sufficient to wet approximately 1 square foot of ground near the left rear wheel occurred upon impact. Examination of the vehicle disclosed that the projecting flange on the filler cap had been struck by the rear filler well structure as shown in Figure 5-50, loosening the cap and allowing fuel to surge from the filler at impact. Although the amount of spillage was small, it should be considered hazardous since vapor spray could easily form a flammable fuel/air mixture. This mixture could travel to potential outside ignition sources in the area.

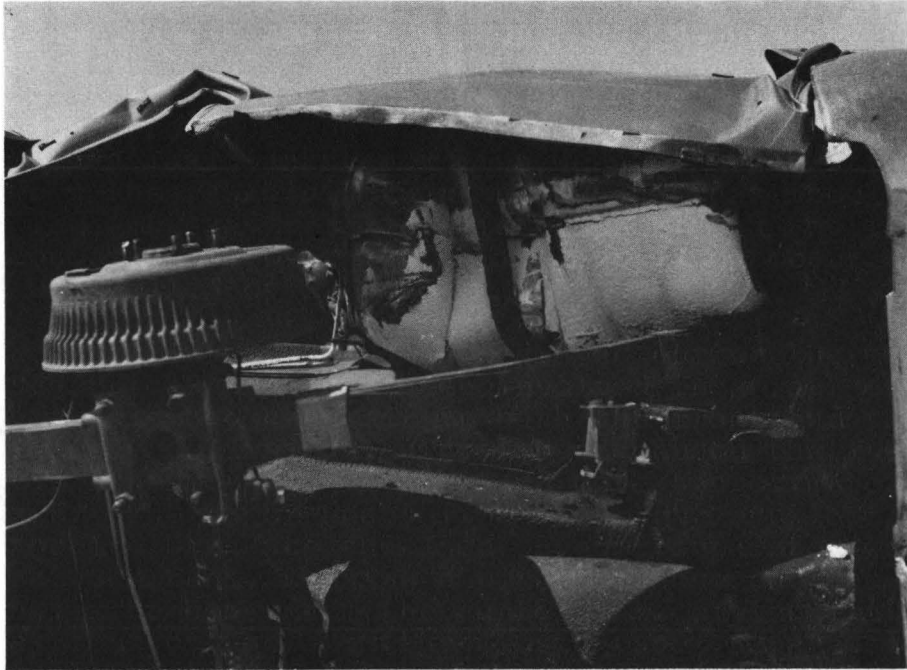


Figure 5-49. Fuel Tank in Dodge Station Wagon Following Barrier Test.

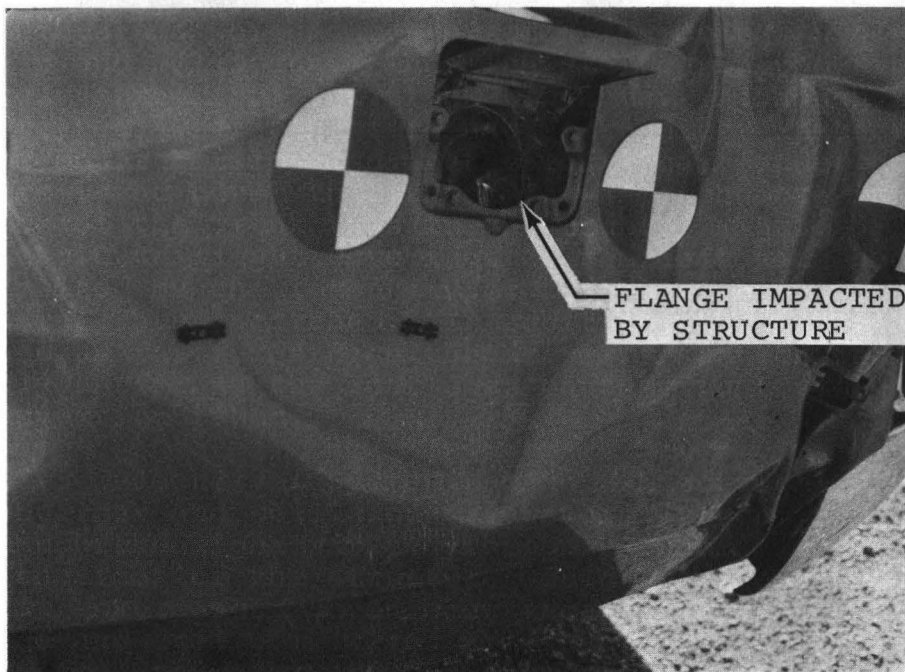


Figure 5-50. Post-test View of Dodge Station Wagon Filler Cap.

Damage to evaporative control system components during a rear end collision depends upon the location of the components in relation to the vehicle structure and other vehicle components. Two examples of vapor hose failure were observed during the barrier impact tests. One involved the broken Toyota vapor line-tank connection discussed above and the other occurred in the Ambassador when a fuel tank vapor line was torn when it was trapped between the vehicle structure and the rear shock absorber or spring. The Ambassador failure is discussed in Section 5.3.4.2 (Secondary Roll-Over) as no fuel spillage occurred until the vehicle was rolled over.

Vapor hose failures were also observed during the examination of a 1970 Buick which had been involved in a rear end accident. This vehicle had been hit in both the front and the rear, typical of freeway collisions. The impact caused the fuel tank to break out of the mounting straps and move approximately 6 inches forward. The vapor hoses from the right and left front corners of the fuel tank to the liquid-vapor separator were both sheared off at the tank, leaving a piece of hose and the clamp with the tank. The hose from the center rear of the fuel tank did not break, but pulled from the liquid-vapor separator with the clamp still attached to the hose.

It is probable that fuel would surge through a broken fuel tank vapor line during crash impact, as occurred in the Toyota. Released vapor from a liquid-vapor separator could also be quite hazardous as the vapor easily forms a volatile fuel/air mixture. Escaping vapors from broken lines to the separator or fuel tank could also intensify a fire once it had started. Figure 5-51 shows a 1970 Mustang which caught fire after being involved in a moderate rear end collision. The fire started in the trunk area and completely burned out the trunk contents. Although it was impossible to tell where the fire had started, or whether the liquid vapor separator located in the left rear fender had been broken, there is no doubt that the fire was much more intense in the left side of the trunk than in the right. Figure 5-51 shows that the plastic taillight coverings on the left side had been completely melted by the intensity of the fire while those on the right had barely been scorched. In addition, the interior headlining burned as far forward as the driver's seat on the left side but only as far as the rear seat on the right side before the fire was extinguished.

5.3.2.2.3 Electrical System Damage. Electrical system damage during rear end collisions is generally confined to broken taillight and brake light wires. The only other electrical components in the rear of the structure would be wires to the fuel gages and, in some cases, to an electrical fuel pump. However, the fuel gage and fuel pump wires are generally routed from the front of the fuel tank forward and are fairly well protected during a rear end collision. However, the rear light wires are



Figure 5-51. Fire Damage in 1970 Mustang Involved in Moderate Rear End Collision.

in exposed locations and quite often are severed during impact. Sparking of the severed wires if the circuit is energized could easily serve as a fire ignition source.

Most of the rear collision wiring failures noted during the crashed vehicle analyses consisted of wires being cut by sheet metal structure. There were several collisions examined, however, in which no damage to the wiring occurred. This was especially true when the vehicle wires were formed into a well sheathed cable. In the case of the Toyota, for instance, the cable was strong enough to resist cutting. In addition, the deformation of the vehicle structure pulling on the cable separated the quick-disconnect which leads to the power supply. The power supply male lead was still shielded within a plastic connector and thus no sparking would have occurred during the separation.

5.3.2.2.4 Exhaust System Damage. Exhaust system damage during a rear end collision generally consists of the tail pipe being bent and, in some instances, torn. The only instance in which exhaust system damage other than direct impact damage was observed was in the barrier test of the Pinto. The tail pipe in the Pinto is routed up and over the rear axle. As the rear of the vehicle was pushed in, the tail pipe was bent upward and pulled to the rear, pulling it loose from the clamp which attaches it to the manifold exhaust pipe (see Figure 5-52). A very definite ignition source threat exists from a failure of this

type, not from the exhaust pipe being hot enough or from hot exhaust gases igniting the fuel, but from the abrading of the loose pipe on the pavement as the vehicle is moving, thus generating friction sparks which could ignite any spilled fuel. The failure of the exhaust pipe along with the fuel spillage from the punctured fuel tank poses a serious fire threat in the Pinto.

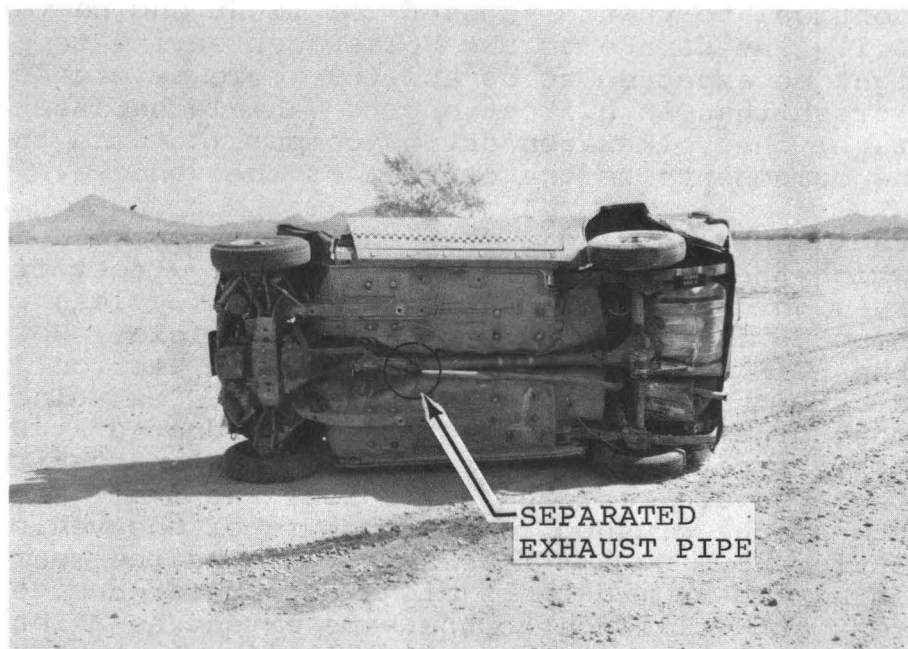


Figure 5-52. Exhaust Pipe Separation in Barrier-Tested Pinto.

5.3.2.3 Non-Crashed Vehicle Analyses. Most of the hazards uncovered during the non-crashed vehicle analyses were observed in the crashed vehicles and are discussed above under impact damage. This includes the damage to be expected by rear-mounted fuel tanks (which are present in the majority of the vehicles analyzed) and damage to the vapor components located in the rear of the car. Those vehicles which contain the liquid-vapor separators in or near the trunk of the car (1970 Fords, 1970 and 1971 Chryslers, 1971 Dodge Colt, and 1971 Vega) would be expected to be more susceptible to vapor component damage than those vehicles which contain the separator farther forward (Cricket, 1970 and 1971 Chevrolets, 1970 and 1971 American Motors, and 1971 Fords). However, as seen in the barrier test of the Ambassador, the potential for failure also depends on the location of the vapor components with respect to other components in the vehicle structure.

There are two common fuel system configurations which were analyzed that were not discussed in the previous sections. These are the rear engine passenger car with the fuel tank in the front of the vehicle and the standard Ford sedan which contains the fuel tank underneath the car in the step-up area just behind the rear axle.

The damage expected during a rear end collision with a Volkswagen Beetle or Super Beetle (which have rear-mounted engines) would be identical to that discussed for front engine vehicles in Section 5.3.1. The damage to the Volkswagen engine compartment, however, might be expected to be a little more severe during a comparable crash than in a front engine vehicle because of the smaller size of the Volkswagen engine compartment and the proximity of the components to the outside of the vehicle.

Fuel tank damage during a rear end collision with a Ford sedan, in which the fuel tank is approximately 3 feet from the rear bumper, might be expected to be considerably less than in a fuel tank mounted in the extreme rear of a vehicle. However, the data from the ACIR accident files discussed in Section 2 (Background) indicate that this type of fuel tank is as vulnerable to damage as most others. Rear impact tests conducted at Dynamic Science on this type of fuel system configuration confirm these data. During a severe rear end collision, the fuel tank is crumpled between the crushed rear structure of the vehicle and the differential housing and rear axle, just as the rear-mounted fuel tanks are. These mid-tanks might not suffer damage in a low-speed rear end collision to the same extent as a rear-mounted fuel tank, but during a more severe collision the type of failure would be comparable to that for a rear-mounted fuel tank with a side filler. Although these tests were run on 1968 vehicles, there is no reason to expect that the performance of the 1970 and 1971 vehicles would be different since they are structurally similar.

5.3.3 Side Impacts. Several vehicles involved in moderate to severe side impact collisions were examined and no fuel system damage was found in any of the vehicles. Figure 5-53 shows typical damage sustained in these collisions. This vehicle received a severe impact at the right front door which pushed the vehicle structure completely away from the fuel and vapor lines routed under the right side of the car. The lines were not damaged because of the common tendency of the striking car to override the bottom structure of the struck car.

Side impacts in the front or rear quarter panels of a vehicle, however, can often lead to fuel system damage depending on the location of the fuel system components within the vehicle. Most station wagon fuel tanks, for instance, are susceptible to extensive damage from a rear quarter impact due to their location in the rear quarter panel. Figure 5-54, a typical station wagon



Figure 5-53. Typical Side Impact Damage.

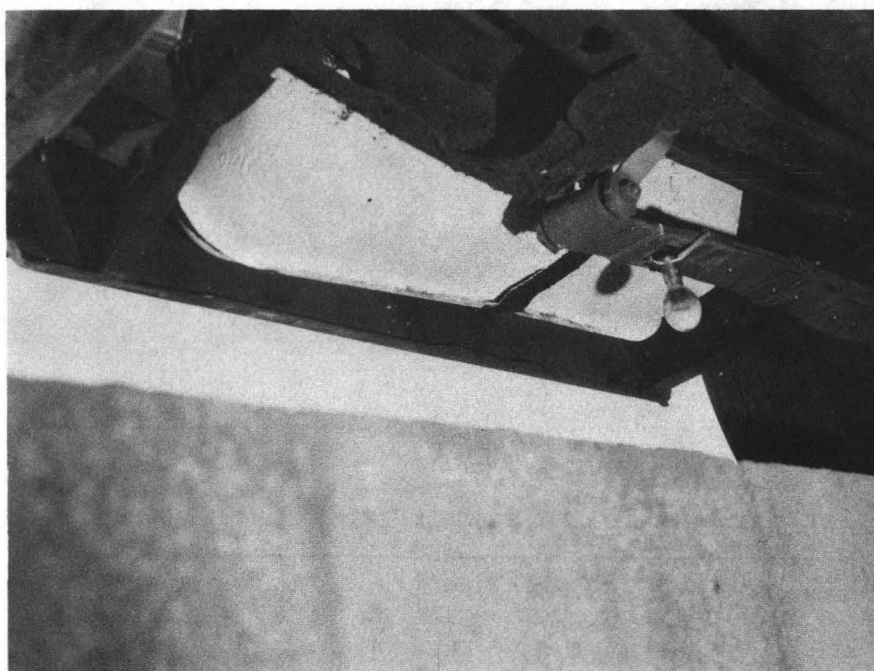


Figure 5-54. Typical Station Wagon Fuel Tank Installation.

fuel tank installation, shows that no protection other than the body sheet metal is available to help reduce damage to the fuel tank during an impact in this area.

Most fuel tanks located under the rear of the vehicle are somewhat protected from side impact damage by their central location and a fairly severe rear quarter impact would be necessary to damage them to any great extent. The Chevrolet Vega fuel tank, however, is located behind the rear tire and axle very close to the right side of the vehicle (see Figure 5-55). Damage to the tank could be expected to be quite extensive during a moderate to severe right rear quarter impact as the tank would be crushed between the impacting vehicle and the body structure to the left of the fuel tank.



Figure 5-55. Chevrolet Vega Fuel Tank Installation.

An impact in the rear quarter panel containing a side filler could deform the vehicle structure to such an extent that the filler neck could be pulled from the tank or from the filler cap attachment to the structure. This type of damage would tend to occur more readily in those vehicles possessing rigid filler necks (e.g., Ford sedan and Pinto) than in those containing flexible fillers (e.g., Volkswagen, Ambassador, and Ford Ranchero). However, if the connections between the flexible and rigid sections of the filler neck are not adequate, they also may be pulled loose during structural deformation.

The liquid-vapor separators which are located in the rear quarter panel (1970 Fords, 1970 and 1971 Chryslers, 1971 Colt, and 1971 Vega) are also subject to rear quarter impact damage because of their location. Even if the separators themselves are not damaged, the structural deformation may easily be enough to pull the vapor lines between the tank and the separator loose. Should this happen, liquid fuel could be sprayed through the hoses by hydraulic surge within the tank during impact.

Impacts in the front quarter panels would lead to damage similar to that discussed under front impacts. Most of the carbon canisters are located near the side of the engine compartment as are the batteries. These components would therefore be subjected to damage during a front quarter impact as well as a direct frontal impact. The front fender vapor storage tanks in some Toyotas would also be highly susceptible to front quarter impact damage.

One severe sideswipe accident involving a 1970 Volkswagen Beetle was also analyzed during this program. Although both right front fenders had been almost torn off and the right side of the passenger compartment pushed in several inches, no damage was sustained by the fuel or the evaporative emission control system. The filler, expansion tank, and carbon canister located on the right side of the car were all mounted inboard of the wheels and thus escaped damage.

One sled test was conducted to assess the integrity of the Toyota Corolla evaporative control subsystem and several Ford, General Motors, and Volkswagen components to side impact accelerations (Appendix F). None of the components nor their attachments were damaged. However, some fuel sprayed from the Toyota side filler during the impact. This vapor spray could easily reach ignition sources in the engine compartment of the striking vehicle in a rear quarter impact on the filler side and must be considered a definite fire hazard.

5.3.4 Roll-Over Accidents. Fuel system fire hazards which might be incurred during a roll-over accident were determined from vehicle analyses and from roll-over and pitch tests which are described in detail in Appendices D and E. Although the pitch tests consisted of elevating first the front end and then the rear end of an undamaged vehicle to a maximum of 60 degrees, most of the information gained during these tests could be applied to a roll-over as the pressure head of fuel generated during the pitch tests was comparable in many instances to the head of fuel which would be generated during a roll-over. The roll-over tests were all conducted with vehicles which had previously been front impact barrier tested to provide support data for the proposed amendment to FMVSS 301, which specifies no fuel leakage during a roll-over test performed after the vehicle has impacted a fixed collision barrier. The roll-over tests, although

conducted on damaged vehicles, still provided a valid assessment of those fuel system components which were not damaged.

The following analysis is divided into two types of roll-overs: principal (vehicle rolls without first colliding with another vehicle or object) and secondary (the vehicle rolls following a collision).

5.3.4.1 Principal Roll-Over. Fuel spillage may occur during a roll-over accident even though the fuel system is not damaged. Spilling of the carburetor float bowl contents during a roll-over has been a common occurrence for some time and is not unique to the new systems studied in this program. That this still happens with the modified carburetors used in new systems was confirmed by the roll-over tests conducted during this program.

Fuel spillage occurred from all of the carburetors which had not been damaged during the barrier crashes. There was some minor variation, however, in the vehicle attitude at which spillage occurred. For instance, the Chevelle spilled all of the fuel from the carburetor float bowl as it was first rotated onto its side (the left side in this case). The Ambassador also spilled some fuel from the carburetor when it was rolled on its left side but did not completely empty the float bowl until it was further rotated onto its top. The Pinto and Dodge, on the other hand, did not spill any fuel from the carburetor until they were rotated past 90 degrees onto their tops. The fact remains, however, that fuel was spilled from all of these carburetors during a roll-over.

This fuel spillage must be considered particularly hazardous as it occurs in the engine compartment which contains numerous potential ignition sources. As noted in the discussion on front impacts (Section 5.3.1), many of the batteries are located very close to the front quarter panel of the vehicle and a small amount of structural deformation in this area resulting from the roll-over could easily result in contact between the battery terminals and the structure, thus generating a spark which could ignite the spilled fuel. The possibility also exists that the battery could be completely displaced from its position due to inadequate mounting provisions. Displacement of the battery would result in a high probability of sparks occurring from contact between the terminals and vehicle structure.

Fuel spillage may also occur during roll-overs from the pressure relief valves incorporated in the filler caps. This type of spillage occurred in 50 percent of the vehicles containing these valves which were subjected to the roll-over and pitch tests. The fluid pressures and spillage rates during these tests are shown in Table 5-V. The results are consistent with the pressure relief valve designs, i.e., open under pressures ranging from .5 to 1.0 psi.

TABLE 5-V. FILLER CAP PRESSURE RELIEF VALVE SPILLAGE DURING ROLL-OVER AND PITCH TESTS			
Vehicle	Vehicle Position	Approximate Fluid Pressure (psi)	Spillage Rate (fluid oz/min)
Roll-Over Tests			
1970 AMC Ambassador	Left Side	1.5	<0.5
1970 Chevelle Malibu	Top	0.2	None
1971 Ford Pinto	Left Side	1.0	0.5
1971 Dodge Station Wagon	Top	0.6	0.03
Pitch Tests			
1971 Chevelle Malibu	60° (Front Up)	0.9	None
1971 Ford Mustang	60° (Front Up)	0.7	None
1971 Plymouth Satellite	60° (Front Up)	1.0	Seepage Only
1971 AMC Hornet	45° (Front Up)	0.8	0.2
1971 AMC Hornet	60° (Front Up)	1.0	0.7

The pressures attained during a roll-over accident depend upon the shape of the fuel tank and the location of the filler cap. During the roll-over tests, all of the vehicles except the Chevelle contained side fillers. The only position in which the Ambassador and Pinto leaked was on the left side where the fillers are located. Thus, spillage occurred only when the fluid pressure head in the tank was at the maximum possible. The same situation was true for the Dodge station wagon which only leaked when it was on its top, i.e., when the fluid head against the pressure relief valve was at a maximum. The Chevelle, with a rear filler and a shallow flat tank, had very little pressure applied to the filler cap in any of the roll-over attitudes and thus no spillage occurred.

All of the vehicles listed in Table 5-V which were subjected to the pitch tests contained shallow tanks with rear fillers. The Satellite and Hornet did not spill any fuel from the relief valve until they were elevated to the extreme positions listed in Table 5-V. It is therefore unlikely that these vehicles would

spill any fuel during a roll-over as the fluid pressure head would not be sufficient to open the relief valve. If these vehicles should come to rest in an extreme front-up attitude following an accident, however, fuel spillage could occur.

All of the spillage rates from the filler cap relief valves were small and, since most of them occurred only at the highest fluid pressure which would be encountered in the vehicle, these spillage rates should represent the maximum spillage rates which could occur from the relief valves. Although the spillage rates are small, the danger does exist that this fuel could be ignited by an outside ignition source or possibly by sparking taillight wires broken during the roll-over. In addition, the structural deformation which occurs during a roll-over accident can result in entrapment of the occupants and an increase in the time required to free them. During this time, a sizeable amount of fuel could accumulate under the car and result in a catastrophic fire if ignition occurred.

Fuel spillage can also occur from around a sealed filler if the cap does not seat firmly enough against the filler tube to seal the gasket, as is the case with the Volkswagen Super Beetle. As noted in Section 5.2.4, fuel spillage occurred from around the Super Beetle cap during severe cornering maneuvers with a full tank of fuel. Thus, one would also expect spillage from the filler cap during a roll-over accident and this was substantiated during the pitch tests. When the front end of the Super Beetle was raised 45 degrees forcing fuel against the filler cap, fuel began spilling from the cap at a rate of 1 ounce per minute. This flow rate continued as long as the vehicle was elevated at or above this angle. Since the filler cap is located above and to the right of the fuel tank, leakage would also be expected whenever the vehicle is inverted or on its right side.

Since many of the evaporative control systems are open to the atmosphere through the carbon canister located in the engine compartment, the systems were analyzed to determine if fuel could flow from the tank through the vapor line and be spilled in the engine compartment during a roll-over. The only systems analyzed in which this would not be possible are the Chrysler and American Motors systems, which route the vapors directly into the crankcase, and the Toyota system which contains a purge control valve to shut off the vapor line when the engine is not running.

The new vehicle analyses showed that the flow of fuel through the vapor line to the canister would be highly unlikely in most undamaged systems due to the system designs. The 1970 and 1971 Chrysler, 1970 General Motors, and 1971 Ford vehicles all incorporate narrow orifices (.05 to .06 inch) in the vapor outlet line in the liquid-vapor separator. These narrow orifices would effectively block any significant amount of fuel flow through the vapor lines. American Motors vehicles employ a liquid check valve in the vapor line which would also effectively

block liquid flow. In other systems, such as the 1970 Fords, the Dodge Colt, and the Volkswagen, no fuel would be spilled from the vapor line with the vehicle on its side because of the location of the liquid-vapor separator on one side of the car and the canister on the opposite side. Fuel flow through the vapor line would also be unlikely with these vehicles resting on their tops as the vapor line would be slightly higher than the fuel tank in this position. Some of the 1971 General Motors vehicles (Chevrolet sedan, Chevrolet station wagon, larger size Oldsmobiles, and the Vega) incorporate a restrictor in the hose connection between the liquid-vapor separator and the vapor line to the canister. This restrictor, which contains a narrow orifice, serves the same purpose as the restrictors found in the liquid-vapor separators of some of the other vehicles. It could not be determined during this study if all of the 1971 General Motors vehicles incorporate this restrictor in the vapor line.

The results of the roll-over and pitch tests confirmed the analyses as no leakage occurred in any of the systems with the exception of the 1971 Chevelle. When the rear end of this vehicle was raised to 45 degrees, fuel began running from the bottom of the carbon canister at a rate of 52 fluid ounces per minute. This fuel flow is shown in Figure 5-56. This flow rate continued until approximately 3 gallons of fuel was lost, at which time the flow stopped.

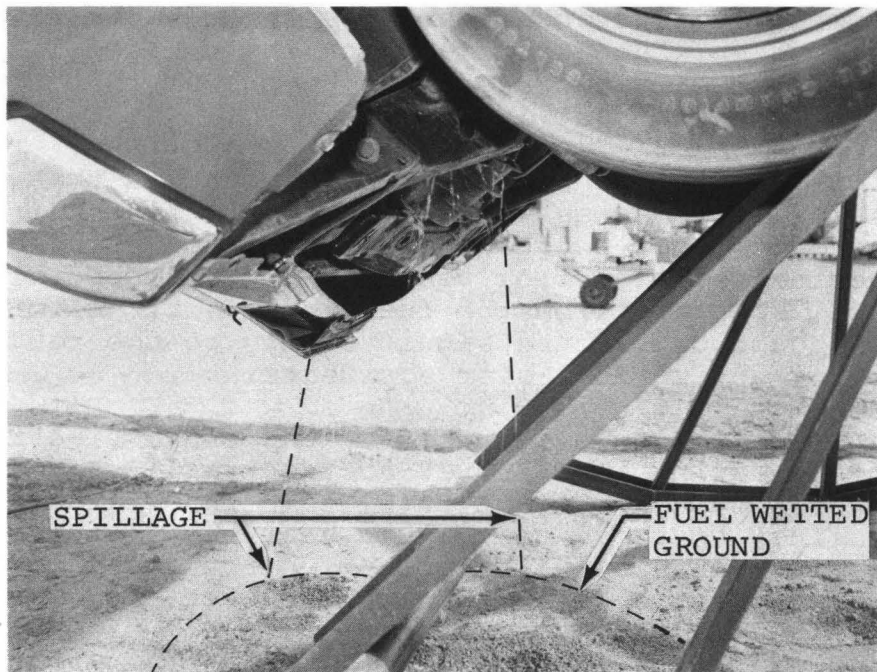


Figure 5-56. Fuel Spillage From Chevelle Canister With Vehicle in 45-Degree Nose-Down Position.

The fuel spillage occurred as the liquid-vapor separator, which is located above the forward end of the fuel tank (behind the rear seat), filled with fuel and allowed the fuel to flow through the vapor line to the canister which is open to the atmosphere at the bottom. As soon as the fuel level in the tank dropped below the top of the standpipe inside the separator, fuel flow ceased. If this vehicle should roll on its left side, the same type of leakage would occur as the vapor line and canister are located on the left side of the vehicle. Leakage would also occur if the vehicle were resting on its top with the front end slightly lower than the rear.

The high flow rate of fuel from the Chevelle during the pitch test made it obvious that a restrictor is required in the line. The same type of fuel spillage would occur in any of the other 1971 General Motors vehicles if the restrictor were inadvertently left out of the vapor hose either during manufacture or replacement of the hose. The incorporation of the restrictor in the liquid-vapor separator itself, as is done in some of the other vehicles, would eliminate this possibility.

Any break present in the vapor hoses between the fuel tank and the separators prior to an accident could also lead to significant amounts of fuel spillage from the fuel tank during a roll-over. This was illustrated with the American Motors Hornet in which the rubber vapor hose had been burned almost through where it had come in contact with the tail pipe (see Section 5.2.5). When the rear end of this vehicle was elevated to 45 degrees allowing fuel to enter the hose through the tank vent line, major fuel spillage occurred from the damaged line as shown in Figure 5-57. Fuel would also have been lost through this line during a roll-over accident.

One significant fact that should be noted is that the evaporative control systems, as long as they maintain their integrity, have eliminated a major source of fuel spillage which occurred in roll-over accidents in earlier vehicles not equipped with these systems, i.e., spillage from the fuel tank vent. Elimination of this hazard should contribute significantly to the reduction of fires occurring during roll-over accidents.

Damage which could be incurred by the fuel, electrical, and exhaust systems during a roll-over accident will, of course, depend on the particular accident involved. In general, any damage would be confined to those components near the periphery of the vehicle and, if collision with another object does not occur, could be expected to be fairly minor. However, if the battery is displaced during the roll-over, it would in all probability be severely damaged.

There is, however, a particularly hazardous type of fuel system damage that can occur during a roll-over with a pickup truck. The filler neck and cap generally protrude approximately



Figure 5-57. Fuel Spillage From Damaged Vapor Hose in AMC Hornet.

1-1/2 inches beyond the vehicle body structure and, during a slide on the left side of the vehicle containing the filler neck and cap, the cap may be torn off or the filler neck broken, leading to massive spillage from the fuel tank. This is particularly hazardous since the sliding of the metal components on the pavement would generate friction sparks which could easily ignite this fuel. Since the fuel tank is located in the occupant compartment of the truck, chances for occupant survival if a fire occurs are very slim.

5.3.4.2 Secondary Roll-Over. The fire hazard occurring during a secondary roll-over is dependent upon the fuel and electrical system damage incurred during the initial impact. As was discussed in Section 5.3.1, front impacts will often result in damage to the battery and to fuel lines in the engine compartment. In many instances, fuel leakage will not occur from damaged fuel lines until the vehicle is rolled over. For instance, the American Motors Ambassador which suffered a broken fuel line fitting during the front barrier test did not leak after the test as long as the vehicle was upright. However, a continual stream of fuel (44 ounces per minute) flowed from the broken fuel line fitting as soon as the vehicle was rotated onto its left side, as shown in Figure 5-58. Spillage continued at the same rate when the vehicle was inverted. The natural resting position of the vehicle on its top placed the fuel tank above the broken fitting (Figure 5-59), and thus the complete contents of the fuel tank

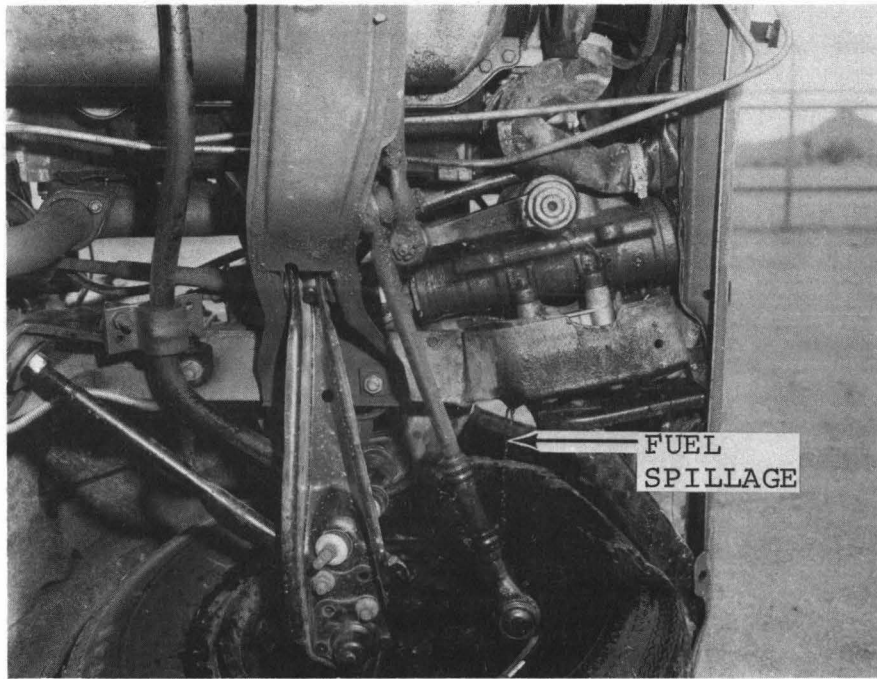


Figure 5-58. Fuel Spillage From Broken Fuel Line in AMC Ambassador.



Figure 5-59. Inverted Resting Position of AMC Ambassador.

would have been drained if the leakage had been allowed to continue. No fuel was spilled from the line with the vehicle on its right side because the fuel line is routed on the left side of the car and was above the fuel tank in this position.

An example of a particularly hazardous situation during a roll-over following a front end impact was found during the roll-over test conducted on the Pinto. When the vehicle was turned on its right side, fuel spilled at the rate of .2 ounces per minute from the decelerator valve-carburetor hose which had been partially severed during the front end impact. The spilled fuel impinged directly on the damaged battery. This fuel could have been easily ignited by sparks from the damaged battery and, although the total amount of fuel spilled was not great, the fuel fire could have easily ignited other flammable fluids or materials in the vehicle.

Fuel system spillage during a secondary roll-over following a rear end impact also depends on the damage caused by the initial collision. If the fuel tank itself is damaged during the rear impact, spillage will continue as the vehicle rolls. This was demonstrated with the Pinto and Chevelle in which spillage continued at the same rate when they were rolled on their left sides as when the vehicles were upright.

As in the case of roll-overs after front impacts, roll-overs following rear end impacts may produce spillage from damaged components which did not leak when the vehicle remained upright. This was demonstrated when the Ambassador and the Toyota were rolled on their left sides following the barrier impact. Fuel spillage at a rate of 14.4 ounces per minute was observed from a broken vapor line in the Ambassador (Figure 5-60). The rubber section of the vapor line leaving the right front corner of the tank had been torn where it connects to the metal portion of the line leading to the liquid check valve (see Figure 5-61). This tear occurred approximately 6 inches from the tank outlet and was apparently caused by the hose being caught between the crushed vehicle structure and the right rear shock absorber or spring. Most of the fuel in the tank eventually flowed out through this broken line.

Fuel spillage also occurred from the separated fuel line (see Figure 5-48) in the Toyota when it was rolled onto its right side. The spillage rate measured 10 minutes after the car had been turned on its side was 5.1 ounces per minute, and the entire contents of the fuel tank eventually flowed out through this line. It should be noted that the break in the line occurred downstream of the electric fuel pump which is located at the right side of the fuel tank. Apparently, the pressure head of fuel in the tank was sufficient to force the pump open and allow the fuel to flow through. No spillage was noted when the Toyota was rolled on its right side before the rear end impact. The then undamaged fuel

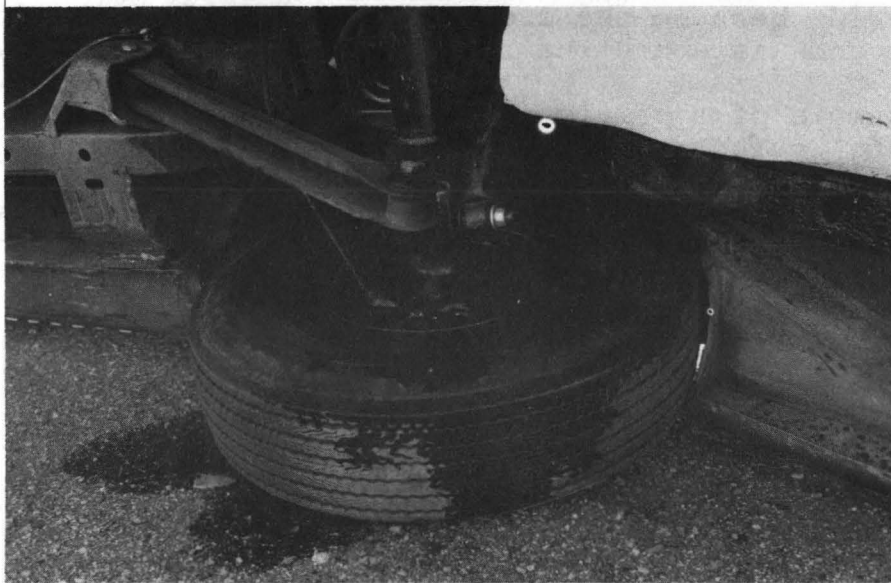


Figure 5-60. Fuel Spillage From Damaged Vapor Hose in AMC Ambassador.

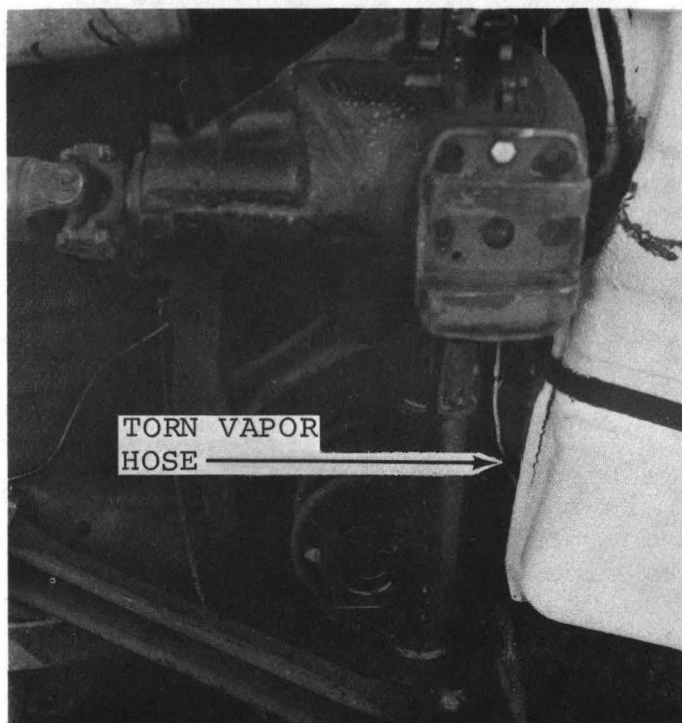


Figure 5-61. Vapor Hose Damage in Ambassador From Rear Barrier Test.

line is routed to the left side of the vehicle to enter the carburetor and is as high or higher than the fluid level in the fuel tank when the vehicle is on its right side.

No leakage occurred from the Dodge station wagon when it was rolled onto its right side. However, had this vehicle been rolled onto its left side, fluid spillage from the tank would have undoubtedly occurred through the filler cap which was loosened during the rear end impact.

Although the numerous high energy ignition sources present in the engine compartment are not present during a rear end accident, except from the striking car, the large amounts of fuel which may be spilled from the fuel tank make vehicles rolled subsequent to rear end impacts susceptible to outside ignition sources for some time following the impact. The possibility also exists that the spilled fuel could be ignited by sparks generated from broken taillight wires contacting the vehicle structure or from friction sparks generated as the vehicle rolls over.

5.4 SUMMARY AND CONCLUSIONS

5.4.1 Operating Conditions. The majority of the evaporative emission control systems present no increase in the fire hazard as long as the systems remain intact and function as designed. The systems provide adequate venting of the fuel tank at all normal operating attitudes, adequate expansion space for liquid fuel expansion due to increasing temperatures, and adequate provisions for preventing liquid fuel from entering the vapor system under all operational attitudes.

The only basic design deficiencies found during this program were in the American Motors Rebel and the Ford Pinto. The placement of the Rebel (and Ambassador) liquid check valve on the same side of the vehicle as the filler cap containing the pressure relief valve will allow a pressure buildup in the tank if the car is parked in certain attitudes. The cause of engine compartment fires which occurred in the early Pintos (too high a vapor flow rate into the air cleaner) has been corrected by the installation of a plug in the air cleaner inlet. The early Pintos were recalled by the Ford Motor Company for retrofit installation of this plug which is now a standard part of the Pinto system.

A question does remain on the adequacy of the vapor storage containers to contain all the fuel vapors generated over extended soak periods. This problem could not be fully assessed during the program and could conceivably lead to an increase in engine compartment fires as compared to those incurred by the pre-evaporative emission control system vehicles.

The use of the evaporative emission control systems, however, could lead to increased spillage problems as the vehicles age due

to the complexity of many of the systems and associated maintainability problems. Failure of the vapor lines can definitely be identified as a future problem since several instances of material degradation and chafing of the lines were found during the examination of several low mileage vehicles during this program. In other instances visual inspection revealed potential vapor line failure points. The possibility for accelerated degradation and chafing of the lines depends on the location of the lines with respect to the vehicle structure and other vehicle components. Thus, every make and model of vehicle would have to be examined to determine the full extent of this problem.

Simplifying the systems with an eye to reducing the number of components would help alleviate maintainability problems. Simplification of the 1971 Ford evaporative emission control system as compared to the 1970 Ford system is a striking example of what can be done in this respect.

Many of the system failures and malfunctions which could occur during operating conditions would affect engine and vehicle performance but would not necessarily constitute a fire hazard. For instance, a collapsed fuel tank in itself does not necessarily pose a fire hazard. Other evaporative emission control system failures, however, could be quite hazardous. A hazardous situation would arise if fuel or vapor escaped from the system and accumulated in an enclosed area, such as the trunk, passenger compartment, or engine compartment. In such an enclosure the fuel vapors could form a flammable fuel-air mixture for eventual ignition by shorted wires within the vehicle or by outside ignition sources, especially during an accident.

Another very hazardous condition could arise should any of the vapor lines between the tank and the liquid-vapor separator develop leaks. Fuel could be spilled from the tank through the damaged line during severe maneuvering forces or during crash conditions even though the fuel tank itself is not damaged.

5.4.2 Crash Conditions. Vehicle structural damage during both front and rear barrier impacts at 30 mph is quite extensive. Front end structural crushing seems to be independent of the kinetic energy of the impacting vehicle, while the limited number of rear end crashes conducted during this program indicated that rear end structural crushing was directly proportional to the kinetic energy of the vehicle (with the exception of a station wagon).

This program afforded a unique opportunity to compare the front and rear end structural stiffness of the same vehicle. The kinetic energy and crush distance of five vehicles during both front and rear barrier tests is shown in Table 5-VI. The amount of crush distance per 10,000 ft-lb of kinetic energy (structural stiffness) was calculated for each test and the ratio

TABLE 5-VI. CRUSH DISTANCE PER KINETIC ENERGY INCREMENT -
FRONT AND REAR BARRIER IMPACTS

Vehicle	Kinetic Energy (ft-lb)		Crush Distance (in.)		Crush Distance per 10,000 ft-lb K.E. (in./10,000 ft-lb)		Rear*- in./10,000 ft-lb
	Front	Rear	Front	Rear	Front	Rear	Front*- in./10,000 ft-lb
Toyota Corolla	55,000	71,800	15-3/4	24-1/4	2.86	3.38	1.180
Dodge Station Wagon	138,000	148,100	28	20-1/2	2.03	1.38	0.680
Chevelle Malibu	97,000	66,600	23-1/4	23-1/2	2.40	3.53	1.470
AMC Ambassador	105,700	62,000	17	20-3/4	1.61	3.35	2.080
Ford Pinto	59,000	36,400	22	13	3.73	3.57	0.957

*This parameter can be considered a front/rear stiffness ratio.

between the front and rear tests was determined. These values are also presented in Table 5-VI.

Examination of Table 5-VI shows that the crush distance per kinetic energy increment was very similar for all the vehicles, with the exception of the station wagon, during the rear end crashes. However, considerable variations occurred in the crush distance per kinetic energy increments during the front barrier tests. The ratio of front-to-rear end structural stiffness for each vehicle shows a marked variation between the vehicles, with the front end stiffer in three vehicles, the rear end stiffer in the station wagon, and almost equal front and rear end stiffness in the Pinto.

The majority of fuel system spillage during a collision results from direct impact damage of the fuel system components. The only spillage that can occur during a crash in which the fuel system integrity is maintained is due to fuel sprayed from around the filler cap or forced from the carburetor. The occurrence of such acceleration-induced spillage is not unique to those vehicles equipped with evaporative emission control systems but also occurs in those vehicles without such systems. Spray from the filler cap, especially during a rear end collision, may be ignited by ignition sources from the striking car. Fuel sloshed from the carburetor may be ignited either by shorted wires or by the hot exhaust manifold of the engine.

The component location in the vehicle determines the type of damage that may be expected during a collision. The extent of the damage depends upon the impact velocity and weight of the colliding vehicles.

Components located ahead of the engine block in front engine vehicles will generally be heavily damaged during a front impact into a barrier at 30 mph. Engine compartment components located at the side of the engine block can also be damaged by being pushed into other components in the engine compartment. Damage may also occur to those components located in the very front of the engine compartment, such as batteries, during a much less severe front end accident.

Vehicles with front fuel tanks will experience fuel tank crushing during a front end impact. The extent of damage, again, depends on the impact speed and the type of object struck. Only one front barrier test was observed with this type of vehicle and no fuel system leakage occurred during the 30 mph impact.

Rear underfloor fuel tanks are particularly susceptible to damage during rear end impacts. Failure can occur either by crushing of the fuel tank between the rear structure of the vehicle and the differential housing or by the fuel tank being punctured by sharp objects on the front of the striking car. Crushing of the fuel tanks does not usually result in splitting of the fuel tank wall or seams except during very severe impacts. However, the crushing of the underfloor tank during moderately severe impacts can lead to the tank being punctured by the differential housing or to the failure of the filler neck-fuel tank connection. Rear filler necks, especially those soldered into the fuel tank, may be damaged during even moderate rear end impacts.

Fuel tanks located under the floor in the step-up area between the rear axle and the trunk are also susceptible to crushing during relatively severe rear impacts. This location might help protect the tank during minor to moderate impacts but the strength of the vehicle rear structure is not sufficient to protect the tank during more severe rear end impacts. The only fuel tank which was not crushed during the rear end barrier tests was one which was located above the rear axle behind the rear seat.

Relative movement between the fuel tank and attached vapor or fuel lines may pull the connecting hoses off of their attachments to the tank or from the rigid lines which run underneath the cars. This type of failure is more common when spring type clamps are used although failures do occur with screw type clamps in cases of severe structural deformation. The snagging of fuel or vapor lines on deformed vehicle structure or other components can lead to tearing of the lines or breaking of the attachments.

Primary roll-overs (those not involving a prior collision) will invariably spill fuel from the carburetor float bowl. Fuel may also be spilled from the pressure relief valve located in the filler cap if the fuel tank configuration is such that the pressure head of fuel exerted against the valve is sufficient to open it.

As long as the fuel feed or evaporative control systems are not damaged during a roll-over, no other leakage should occur with the possible exception of some General Motors vehicles. Testing of a 1971 Chevelle did show that fuel could run from the tank through the vapor line and out the carbon canister if the vehicle were in a steep nose-down attitude or inverted. It was not determined, however, whether this spillage was due to the design of the system or to possible omission of a restrictor in the vapor line.

Fuel system damage resulting from a roll-over would generally not be severe enough to cause spillage unless the rolling vehicle struck an object. However, serious damage could occur in a roll-over in those pickup trucks with a protruding filler cap and neck, especially if the vehicle were to slide on the side containing the filler cap. Damage to the filler or cap would lead to spillage of the tank contents.

Any fuel system spillage during a collision must be considered a fire threat because of the many ignition sources also generated during a collision. A front end impact usually results in a combination of electrical and fuel system damage, thus placing spilled fuel in proximity with sparks generated from electrical system failures. Rear end impacts can result in large amounts of spilled or sprayed fuel being ignited by damaged electrical system components in the engine compartment of the striking car. Roll-over accidents can combine fuel spillage with friction sparks generated from the vehicle structure striking the pavement and/or electrical sparks from displaced batteries. Side impacts seem to be the least hazardous of all vehicle accidents with regard to fires if the impact is centered in the passenger compartment, as the only components located in this area are the fuel and vapor lines under the car and the striking vehicle tends to override these lines without breaking them. Side impacts in the front and rear quarter panels, however, can lead to the same type of damage and resultant hazards as occur during front and rear end impacts.

5.4.3 Conformance to Proposed FMVSS 301. The proposed FMVSS 301 on Fuel System Integrity, issued on August 24, 1970,* would require the following fuel system performance effective January 1, 1972: (1) no fuel spillage from a vehicle with a GVWR of 10,000 pounds or less when it impacts a fixed collision barrier while moving longitudinally forward at any speed up to 30 mph and (2) no fuel spillage from a vehicle with a GVWR of 6,000 pounds or less when it impacts a fixed collision barrier perpendicularly while moving longitudinally rearward at 20 mph.

*Federal Register, Vol. 35, No. 169, August 29, 1970.

Of the five vehicles rear impact barrier tested during this program, three were impacted at speeds close to 20 mph. Only one of these vehicles would have passed the proposed 1972 standard. The other two vehicles exhibited extensive leakage from the fuel tanks. Although one of the vehicles was impacted at 21.8 mph rather than 20 mph, the type of failure would in all probability have occurred at the lower 20-mph speed.

The fuel system performance required under the standard for vehicles with a GVWR of 6,000 pounds or less would be extended, effective January 1, 1973, to a 30-mph rear impact fixed collision barrier test and also a roll-over test after both front and rear fixed barrier collisions. The requirements are, again, no fuel leakage during these tests.

None of the vehicles tested during this program would have passed the 1973 standard for fuel system integrity as fuel was spilled from the carburetor in all the roll-over tests. Even excluding the carburetor spillage, none of the vehicles which were rear end barrier tested would have passed the standard, as all but one exhibited impact leakage and this one exhibited fuel spillage when it was rolled over after the barrier impact. This vehicle would also not have passed the roll-over test after a front barrier impact because of a broken fuel line in the engine compartment.

Although major modifications to the fuel systems must probably be made to enable most current vehicles to pass the rear impact barrier test at 30 mph, many vehicles could probably pass the 20-mph rear barrier test with minor fuel system modifications.

6. RECOMMENDED DESIGN MODIFICATIONS

6.1 GENERAL DESIGN CRITERIA

The recommended design modifications are aimed at minimizing crash damage to the electrical, fuel, and exhaust system since minimum damage has generally been proven to be associated with minimum fire hazard. The results of this study have shown that it is not the crash acceleration forces that cause system damage which may ultimately lead to fire, but rather structural deformation and direct impact, either by outside objects or other vehicle components.

The basic design criteria formulated to minimize component damage are as follows:

1. Keep the system design as simple as possible to reduce the number of components which may be damaged.
2. Locate the system components in those areas least vulnerable to impact damage.
3. Increase the resistance of the components to direct impact damage.
4. Separate the fuel system from the fire ignition sources (electrical and exhaust) as much as possible to reduce ignition possibilities in case of system damage.

Crashworthy fuel systems which completely contain the fuel under severe impact are within the present state of the art and have been installed in many U. S. Army helicopters with a remarkably decreased incidence of post-crash fire. Details of these crashworthy designs may be found in References 12 and 13. The basic components of these systems are briefly described below.

1. Crashworthy Fuel Tanks. These flexible fuel tanks are extremely cut and tear resistant. Their ability to reshape their volume during a crash and their tough wall material enable them to completely contain the fuel even when subjected to direct impacts or when trapped in mangled aircraft structure.
2. Self-Sealing Breakaway Valves. These valves are located at strategic locations in the fuel system and provide known and controllable failure points since they separate at stresses below the strength of the connecting lines. Each half of the valve seals automatically after separation, preventing fuel spillage from the system.

3. Frangible Attachments. Fuel tank leakage often results from a crash because an attachment such as the filler or fuel line was pulled from the tank wall. This type of failure occurs when the structure to which the attachment is fastened displaces in relation to the tank and the attachment to the structure is stronger than the attachment to the tank. Incorporation of a frangible attachment, with strength adequate to meet all operational conditions but which breaks under crash conditions, allows the attachment to break free of the structure during a crash and remain firmly fastened to the fuel tank.

Although the above components were developed specifically for aircraft, the basic concepts are equally applicable to ground vehicles and the incorporation of such a fuel system in a motor vehicle would successfully contain the fuel during motor vehicle accidents. However, desirable as such a system would be, the cost would be prohibitive for its use in the majority of motor vehicles offered for sale to the public. There are, however, many lesser modifications which could be made to the present fuel systems which would significantly improve fuel system integrity in crash accidents as severe as 30 mph barrier crashes. These modifications, although possibly resulting in some initial design change costs, are readily adaptable to mass production methods and could be incorporated in present day motor vehicles. These recommendations are presented in the following sections.

The recommendations are described with those showing the greatest potential for reducing fire hazards discussed first. Thus, the fuel system modifications are presented first since the obvious solution to eliminating post-crash fires is the containment of the fuel. Although electrical and exhaust system integrity can reduce the number of possible ignition sources present during a crash, outside sources, especially those due to friction sparks, cannot be controlled. Thus, fuel containment is the prime factor. Electrical system modifications are presented second since the electrical system does present a much greater threat from an ignition source standpoint than does the exhaust system.

In addition, the recommendations have also been ordered with regard to the expected ease of modification and estimated cost of installation. It should be noted that, although the modifications are presented on a component by component basis, the entire system must be improved in order to significantly increase the system integrity. For instance, merely improving the resistance of the fuel tank to crash damage will not prevent the entire contents of the fuel tank from spilling through a broken fuel line.

6.2 FUEL SYSTEMS

Maintaining the integrity of the fuel tank is probably the most important factor to be considered in the overall fuel system because of the high rate and potentially large quantity of fuel that can be spilled from the tank. Also, the majority of tanks are quite vulnerable to rear impacts. Rear impact collisions have been shown to result in a disproportionate number of fire accidents and burn injuries. Fuel tank integrity can be lost either by rupture of the tank itself or by failure of fittings attached to the tank such as fuel lines or fillers.

Consideration of the fuel system integrity in the engine compartment is also important because of the proximity of spilled fuel to numerous ignition sources present in the engine compartment. The carburetor poses a special problem as it may spill fuel from impact surges and does inevitably spill fuel during a roll-over. Preventing fuel spillage from the carburetor would undoubtedly involve major carburetor design changes and, though desirable, is probably not practical for near term implementation, while other components could be improved much sooner.

The fuel evaporative emission control system components do not present a crash hazard in themselves except where a failure in their integrity also compromises the fuel feed system. In this case, a failure of the evaporative control system becomes a definite hazard.

6.2.1 Fuel Tanks. Fuel tanks located at the rear of the vehicle under the trunk floor are frequently crushed between the rear structure and the differential housing and rear axle components during a rear end collision, making this an undesirable position for mounting the tank. A much safer position is the forward section of the trunk compartment above the rear axle as structural deformation or direct impact does not reach this area except during severe collisions. The fuel tank should not extend to the side of the car but should be cradled between the rear wheels to protect it from side impacts. The tanks should be enclosed in a liquid and vapor-tight compartment with through ventilation and drainage at the bottom. This would prevent liquid fuel or vapors from accumulating in the passenger or trunk compartment. The forward wall of this compartment must be able to maintain its integrity at least as well as present firewalls to prevent any crash induced fuel spillage from entering the passenger compartment and to provide a fire barrier for a reasonable length of time.

The location of the fuel tank above the rear axle would, in all probability, allow the standard metal tank now in use to survive a 30 mph rear barrier impact without failing. Some improvement in the survivable limit of the fuel tank could probably be achieved by making the metal tanks of heavier gage sheet metal

with continuously welded seams. Additional protection could, of course, be afforded by going to a crashworthy tank in this location. The crashworthy tank could be constructed in the same manner as those now being used in crashworthy helicopter fuel systems or could be of the type used in racing cars. Racing car tanks incorporate a flexible bladder and reticulated foam within a standard metal tank. The crashworthy helicopter type of fuel tank is preferred because of its inherently greater tear and puncture resistance as compared to the foam filled bladder tank and the doubtful efficacy of the racing car tanks to reduce fuel tank failure and leakage during severe impacts.

Locating the fuel tank over the rear axle is not recommended for rear engine automobiles as the danger exists that the engine could be pushed into the fuel tank during a severe rear end collision. However, locating the fuel tank over the front axle between the front tires should offer the same amount of protection as the rear axle location. As with the rear axle fuel tank location, the front axle fuel tank should be enclosed in a drained and ventilated compartment which is separated from the passenger compartment by a well constructed bulkhead. The front axle installation should enable a metal tank to withstand a 30 mph barrier crash. Again, if additional protection is necessary as the survivable impact speed of the car is raised, a crashworthy tank might be necessary.

The present location of fuel tanks in the cab of pickup trucks seems satisfactory in relation to front and rear impacts and roll-over accidents. The resistance of these tanks to side impacts is not specifically known, but the higher profile of the truck itself, plus the higher location of the tank within the truck, should protect it fairly well from side impacts by passenger cars. However, the location of the tank with its associated attachments and lines within the passenger compartment definitely calls for enclosing the fuel tank in a liquid and vapor-tight compartment which possesses at least the same degree of collision integrity as does the passenger compartment itself. Again, adequate ventilation and drainage should be provided for the compartment. Enclosing of the fuel tank in this manner would prevent either liquid fuel or fuel vapors from entering the passenger compartment due to failures of the fuel tank attachments and/or lines during operational or crash conditions.

The location of station wagon fuel tanks in the fender wells, although possibly satisfactory up to 30 mph rear barrier impacts, certainly is not satisfactory from rear quarter impacts upon the fuel tank area. The space above the rear axle, of course, is not available in a station wagon and it is not at all obvious that locating the tank under the floor behind the axle would protect it from a direct rear end impact, especially in view of the large amount of structural deformation in this area which was encountered during the 30 mph rear barrier crash with the Dodge station

wagon. Thus, it is entirely possible that the only way to sufficiently protect the occupants of a station wagon from the hazards of fuel tank failures during collisions might be the incorporation of flexible crashworthy fuel tanks, either in the fender or under the rear floor.

6.2.2 Fillers. The filler must be prevented from breaking or pulling from the tank during a collision. Moving the fuel tank from the rear of the car up over the rear axle helps alleviate the previous problems associated with filler neck failures by putting the filler high on the side, away from direct impact in most instances. Putting the filler on top of the rear deck area just behind the rear window would protect it from crash damage to an even greater extent. With either installation, a sealed scupper incorporating an overboard drain must be provided so any fuel spilled during filling operations will not drain into and be trapped anywhere within the vehicle structure.

Even though the filler neck is protected from direct impact damage, structural deformation between the filler cap opening and the fuel tank could still lead to filler neck failure if a completely rigid filler neck is used. This problem can be alleviated either by using a flexible connection at the tank-filler outlet or by incorporating a flexible section between a rigid tank outlet and the filler cap. If a rigid neck and flexible tank outlet connection are used, the filler neck must extend into the tank at least 4 to 6 inches to prevent the neck from being pulled free of the fuel tank. In addition, the flexible grommet must be securely attached to the tank so it cannot be pulled loose. The filler neck must also fit very tightly into the grommet in order to prevent fuel from surging between the filler pipe and grommet during impact.

If a flexible filler and a rigid tank outlet are used, several factors must be considered. The rigid connection to the tank should be welded rather than soldered to the tank for better strength. The flexible section of the filler neck must be made from a material which is fairly resistant to cutting and puncturing, is quite flexible, and possesses good elongation properties. In addition, the hose should be longer than necessary and should be routed in an open area in the structure so it is free to move during structural deformation. The hose must also be securely fastened to both the tank outlet and the filler cap scupper attachment so it will not pull loose at either end. If sufficient elongation and deformation are allowed in the filler neck, this could probably be accomplished by slipping the hose over ridged ends on the attachments, allowing several inches of overlap, and fastening securely with screw type hose clamps.

The filler cap should not protrude beyond the side of the vehicle but should be recessed behind an access door. This would prevent the cap or the end of the filler neck from being torn loose during a collision or a roll-over. In addition, the filler

cap should be completely smooth with no protrusions which could snag on the vehicle structure and either tear the filler or loosen the cap.

Fuel surge leakage around the filler cap gasket during impact could be eliminated by incorporation of a check or anti-surge valve in the filler neck to prevent fuel from entering the filler. The check valve would also preclude fuel entering the filler neck during a roll-over accident. If a check valve is not incorporated, the filler cap seal may be improved by using a threaded filler cap and filler neck similar to those used in aircraft.

6.2.3 Fuel and Vapor Line Outlets. Tank fuel and vapor outlets should be located on the least vulnerable side of the tank to protect them from impact damage. Special care must also be taken to insure that the outlet cannot be impacted by other vehicle components, as happened during the barrier crash of the Toyota. Recessing the outlets below the tank wall contour will also significantly reduce the possibility of the outlets being broken from the tank. All of the outlets should be welded securely to the tank for higher attachment strength rather than being soldered. If ordinary tube outlets are used, these should be long enough to allow the attaching hose to slide over them by several inches and a ridge should be provided around the end of the outlet to further help in retaining the hose. The use of threaded fittings and threaded hose ends would offer significantly improved retention in areas where it is deemed necessary. Crashworthy fuel tanks, of course, will incorporate threaded inserts bonded into the tank wall. These inserts should also be recessed below the overall tank contour.

6.2.4 Fuel and Vapor Lines. Fuel and vapor lines should be routed in protected locations where they cannot be caught in deforming structure or impacted by other components in the vehicle. They should also be routed, where possible, away from electrical system components, the engine exhaust manifold, and the front pipe of the exhaust system. They must also be routed or protected so that chafing cannot occur against any of the vehicle components or structure during operating conditions.

The practice of using flexible hose as a line connection to a component is a sound concept. However, this hose should be protected by flexible metal coils or should be made from the steel braided flexible hose used in aircraft to provide cut and tear resistance during a collision.

Hose connections to tubing outlets on the fuel tank or to sections of metal tubing should be accomplished by sliding the hose several inches over the ridged tubing ends and securing firmly with a screw type hose clamp. Spring clamps should not be used as they cannot maintain the connection during more than minor movement of the hoses and tubing. In addition, the hoses

should be provided with more length than is necessary so they may move with the deforming structure. The hoses can be stabilized to the vehicle structure by frangible attachments which are adequate to keep the hose from chafing during normal conditions but which will separate during crash conditions and allow the hose to move.

Additional crashworthiness and improved operating reliability could be achieved by using steel braided flexible hose for all lines and threaded fittings for all connections, as is the practice in crashworthy aircraft fuel systems.

6.2.5 Fuel Pumps. Mechanically actuated fuel pumps should be moved farther aft on the engine block. Although most of the fuel pumps now in use are small and fairly resistant to impact damage, moving them farther back in the engine compartment will add additional protection and will also help protect the fuel inlet and vapor return line fittings from damage. The location of the fittings on the pump should also be such that they are not susceptible to impact damage from other displaced engine compartment components.

Electric fuel pumps should be placed in the tank to prevent their damage from crash impact and also to eliminate a possible source of leakage in the line between the tank and the pump. A pump shut-off switch should also be provided which is actuated when the engine stops so that fuel cannot be pumped through the fuel line after a collision. An example of such a switch is that used in the Vega which shuts off the pump when the oil pressure drops below a specified level.

6.2.6 Liquid Fuel Expansion Provisions. Fuel expansion space should be provided within the fuel tank rather than in a separate expansion tank. This eliminates the possibility of fuel being spilled from the expansion tank or the lines connecting the expansion tank to the fuel tank should they be damaged during a collision or roll-over.

6.2.7 Liquid-Vapor Separators. The liquid-vapor separator should be designed so it can be mounted directly to the fuel tank. This will eliminate the vapor lines between the tank and the separator and the possibility that damage to these lines could lead to fuel spillage from the tank. The separator should also be as small as possible and mounted in a protected location to further reduce the possibility of impact damage. A good example of such an installation is found in the 1971 Fords.

If a liquid check valve is used rather than a liquid-vapor separator, care must be taken to provide an alternate vapor escape route in case the check valve is blocked by liquid during extreme operational attitudes of the vehicle. The fuel tank vapor vent lines should be routed through the fuel tank itself

and brought out through a single manifold and line to the check valve to reduce the possibility of damage to the vent lines.

Regardless of whether a liquid-vapor separator or a check valve is used, the design of the system must be such that liquid cannot go through the separator into the vapor line to the vapor storage container. The narrow orifices used in the present evaporative control systems seem to satisfactorily block liquid flow into the vapor line. These orifices or restrictors should be located within the separator or the check valve rather than in the vapor line to prevent accidental omission during assembly and to prevent their being pulled from the separator or check valve should the vapor line be pulled loose.

6.2.8 Vapor Storage Containers. A positive means of trapping the fuel vapors until they are actually run into the engine should be provided, as is done with the carbon canisters, rather than storing free vapors in a storage tank which could be damaged during a collision and release the vapors into the atmosphere. The vapor storage and purging system should be as simple as possible to reduce reliability problems with valves and hoses. The purged vapors should be routed into the base of the carburetor or the engine intake manifold rather than into the air cleaner. This should help reduce the possibility of engine backfires or electrical system shorts igniting fuel vapors in the engine compartment.

6.2.9 Pressure-Vacuum Relief Provisions. A properly designed and reliable pressure-vacuum relief valve incorporated in the fuel tank filler cap is an effective means for preventing over-pressurization or collapse of the fuel tank. However, fuel may be forced through the relief valve due to fuel surges within the tank during crash impact. The head of fuel in a roll-over attitude may also be sufficient to open the valve. Therefore, if this type of pressure-vacuum relief is used, a liquid check valve should be incorporated in the filler neck or cap to prevent fuel pressure from opening the valve and allowing fuel spillage during accidents.

6.2.10 Carburetors. The carburetors in most vehicles are fairly well protected from impact damage by being mounted on top of the engine block. If the carburetor is mounted in another location, special care should be taken to prevent its being displaced into other engine components with enough force to break the carburetor body or mounting, thus leading to fuel spillage.

The force fit plugs installed in carburetor bodies should be prevented from vibrating loose by attaching them firmly and positively to the carburetor body, such as by spot welding. This would eliminate engine compartment fires caused by the plugs coming loose during operation and spilling fuel onto the hot engine.

The spillage of fuel from the carburetor during roll-over accidents is a definite hazard because of the many electrical ignition sources which are present in the engine compartment. Undoubtedly carburetors could be designed with liquid check valves which would keep them from spilling the float bowl contents during a roll-over and this should certainly be done. As mentioned at the beginning of this section, however, the redesign of the carburetor and its attendant effect on engine performance might well make this a complex design problem. Therefore, it is recommended that carburetor redesign efforts to prevent roll-over spillage be started as soon as possible.

6.3 ELECTRICAL SYSTEMS

Methods of reducing the electrical system ignition hazard have been recommended in Reference 10. Although the study leading to these recommendations involved pre-evaporative emission control vehicles, the electrical systems in those vehicles are essentially the same as in the vehicles studied during this program. Accordingly, the recommendations are equally applicable to vehicles containing evaporative control systems.

The earlier study (Ref 10) showed that the three basic methods for reducing the electrical system hazard are:

1. Locating electrical system components and wiring away from areas of possible crash impact.
2. Shielding the electrical system components and wiring from crash damage.
3. Inerting of the electrical system before spark producing damage can occur.

These methods will be briefly described below while the reader is referred to Reference 10 for further details.

6.3.1 Location. Locating electrical system components and wiring near the center of the vehicle structure, away from the exterior, would protect these components from crash damage except in the most severe accidents. Much of the wiring and many of the small components, such as the voltage regulator and starter solenoid, could be located near the center of the vehicle. There are several components, however, which must be located near the periphery of the vehicle. These are the alternator/generator, which is belt driven off the crankshaft of the engine, and the wiring to the various vehicle lights. The alternator/generator is sufficiently sturdy that, with properly designed and shielded terminals, it should not constitute a spark hazard during a collision. The wires to the vehicle lights, however, must be protected by shielding or inerting.

The safest location for the battery is under the rear seat as in some rear engine passenger cars. However, this location makes battery maintenance a difficult task. Locating the battery in the back of the engine compartment near the firewall does protect it somewhat from impact if other components cannot be forced into it. However, locating the battery in the rear of the engine compartment would be very difficult for some vehicles because of the limited amount of available space. Thus, shielding the battery from impact damage, as discussed in the next section, is probably the most feasible method of protecting the battery and eliminating the fire ignition hazard from this source. Regardless of the method used to protect the battery, the attachment of the battery to the vehicle structure must be sufficient to prevent its dislocation during collision or roll-over accidents. The results of this program have clearly shown that most battery attachments are inadequate in this respect.

6.3.2 Shielding. All wiring should be encased in a protective cover to increase its resistance to cutting. All terminals in the electrical system should be of the bayonet type and should be designed so that if separation does occur the exposed pins in the connector will be shielded. In addition, the connector should be so designed that the force required for separation is no more than 50 percent of the force required to fail the weakest wire in the connector. This will ensure that the connector will separate before failure of an energized wire can occur.

It is especially important to shield the battery terminals as, even though the electrical system might be inactivated, the battery will remain a prime ignition source if displaced metal or broken wires come in contact with the battery hot lead. Shielding the terminal connections with an appropriate insulating material would reduce the sparking potential of the battery during a minor to moderate collision. However, during a more severe crash, the shielded connections could be pulled loose, thus exposing the battery terminals. For maximum protection, therefore, the battery should be completely enclosed in a nonconductive impact-resistant box which could be made of material such as low density polyethylene. A bayonet type connection should be used between connecting circuitry and the battery terminal cable with a shielded female end on the circuit wire and the male end on the battery cable well recessed within the protective box.

6.3.3 Inerting. The electrical system circuits can be inerted by placing a device in the circuit which would sense the crash impact and open the circuit. The ignition switch circuit could be inactivated by placing such a device in the wire from the hot lead of the battery to the starter solenoid. Another device should be placed in the circuitry between the starter solenoid and the generator to inert the rest of the electrical circuits in case the engine is not stopped by the impact. Although this method will not inert the battery, it will eliminate the

possibility of sparking from broken or disconnected wiring or from damaged electrical system components. The inerting of the electrical system would be especially feasible in those vehicles equipped with passive restraints as the inertia switch is used to trigger the restraint system could also be used to trigger the opening of the electrical circuits.

6.4 EXHAUST SYSTEMS

Current exhaust systems should be classified as secondary ignition sources since the temperature of most of the exhaust system is below the autogenous ignition temperature of the fuel. However, fuel spillage onto the heated parts of the exhaust system can vaporize the fuel, thus creating an ignitable fuel-air mixture. Therefore, the exhaust system should be routed as far from potential leakage sources as possible. The relocation of the fuel tank above the rear axle would eliminate the now common problem of the exhaust tail pipe being located only inches away from the fuel tank.

The thermal reactor systems that are currently being investigated for emission control operate at very high temperatures (1600 to 1800°F). The reactors are insulated to conserve heat and thus increase the efficiency of the reaction. Every effort should be made to insure that this insulation is sufficient to keep the outer temperature of the reactor below the autogenous temperature of the gasoline (600 to 800°F).

Regardless of the type of exhaust system used in the vehicle, the attachment of the exhaust pipe to the vehicle structure should be strengthened to prevent the pipe from breaking free of the vehicle structure and dragging on the pavement, thus creating friction sparks which could ignite spilled fuel.

7. RECOMMENDED SAFETY PERFORMANCE REQUIREMENTS

7.1 GENERAL

The fuel system safety performance requirements recommended herein are based largely on the results of this study, although data from other vehicle studies were also considered in an effort to provide the broadest data base possible. The required collision performance tests all involve full-scale vehicle crash tests rather than other dynamic tests (e.g., sled tests) since this program clearly showed that direct impacts and not acceleration loads cause fuel system damage. The requirements have also been separated where necessary into near term and long term requirements in recognition of the difficulties that might be encountered in modifying a vehicle to meet the more stringent but nevertheless desirable performance criteria. The results of this study have shown that most vehicles could meet the recommended near term requirements by relatively minor modifications to the fuel system, while there are some vehicles which could undoubtedly meet the near term requirements with no modifications at all.

7.2 RECOMMENDED PERFORMANCE REQUIREMENTS

7.2.1 Application. These requirements apply to passenger cars and to multipurpose passenger vehicles, trucks, and buses with a GVWR of 6,000 pounds or less.

7.2.2 Definitions. "Gross Vehicle Weight Rating" (GVWR) means the value specified by the manufacturer as the loaded weight of the vehicle.

"Curb weight" means the weight of a motor vehicle with standard equipment; maximum capacity of engine fuel, oil and coolant; and, if so equipped, air conditioning and additional weight optional engine.

"Fuel spillage" means any fall, flow, or run of fuel from the fuel system, but does not include wetness which clings to a surface in insufficient quantities to cause puddling or dripping from the surface.

"Fuel system" means the fuel supply system and the fuel evaporative emission control system.

"Fuel spray" means the dispersion of fuel droplets into the atmosphere.

"Vapor spillage" means the release of vapor into the atmosphere from any part of the fuel system not specifically designed for vapor release.

7.2.3 Requirements. Each vehicle shall meet the following requirements under the conditions of 7.2.4.

7.2.3.1 Durability Tests. There shall be no fuel or vapor spillage from the vehicle fuel system when the vehicle is driven 50,000 miles in accordance with the test conditions specified by the Department of Health, Education, and Welfare as stated in Control of Air Pollution From New Motor Vehicles, Title 45, Subtitle A, Part 85. The vehicle shall be inspected for fuel or vapor spillage at least every 4,000 miles.

7.2.3.2 • Front End Collisions. There shall be no more than 1 ounce (by weight) total fuel spillage from a vehicle when it impacts a fixed collision barrier perpendicularly while moving longitudinally forward at 30 mph. In addition, there shall be no visible spray from any part of the vehicle and there shall be no fuel spilled on any part of the engine compartment or on any engine compartment component with the exception of the carburetor air cleaner. There shall be no fuel spillage after termination of impact.

7.2.3.3 • Rear End Collisions - Near Term Requirements. There shall be no more than 1 ounce (by weight) of fuel spillage from the fuel system when the vehicle impacts a collision barrier perpendicularly while moving longitudinally rearward at 20 mph. In addition, there shall be no visible fuel spray from the vehicle and there shall be no fuel spilled on any part of the engine compartment or on any engine compartment component with the exception of the carburetor air cleaner. There shall be no fuel spillage after termination of impact.

Long Term Requirements. The above spillage requirements shall be met when the vehicle impacts a fixed collision barrier perpendicularly while moving longitudinally rearward at 30 mph.

7.2.3.4 • Roll-over. The vehicle shall be subjected to a roll-over test conducted after the front and after the rear end fixed barrier collisions. The vehicle shall be revolved 360 degrees on its longitudinal axis and held for 5 minutes at each successive increment of 90 degrees. Rotation time from one position to the next successive position shall be less than 1 minute. The following fuel spillage requirements shall be met during each roll-over test.

Near Term Requirements. No more than 1 ounce (by weight) of fuel shall be spilled from the filler during any period of rotation between each 90-degree increment. Total fuel spillage shall not exceed 2 ounces (by weight) during the entire 360-degree revolution. Spillage from the carburetor float bowl shall be allowed provided that the total fuel spillage from the carburetor during the entire 360-degree revolution does not exceed the amount of fuel contained in the carburetor float bowl at the beginning

of the roll-over test. There shall be no fuel spillage after the rotation is complete and while the vehicle is being held for 5 minutes at each successive increment of 90 degrees with the exception of the carburetor float bowl contents as limited by the preceding sentence.

Long Term Requirements. There shall be no more than 1 ounce (by weight) of fuel spillage from the carburetor and no more than 1 ounce (by weight) of fuel spillage from the filler during the period of rotation between each successive 90-degree increment. Total fuel spillage from the filler or from the carburetor shall not exceed 2 ounces (by weight) during the entire 360-degree revolution. There shall be no spillage from the fuel system while the vehicle is being held for 5 minutes at each successive increment of 90 degrees.

7.2.4 Conditions

7.2.4.1 Durability Test Conditions. The requirements of 7.2.3.1 shall be met under the conditions specified by the Department of Health, Education, and Welfare in Section 85.90, Part 85, Subtitle A, Title 45.* The requirements shall be met without replacing any components of the fuel system except those which are replaced as part of normal maintenance procedures.

7.2.4.2 Barrier and Roll-Over Test Conditions. The requirements of 7.2.3.2, 7.2.3.3, and 7.2.3.4 shall be met under the following conditions:

1. Vehicle Weight. The vehicle shall be loaded to its curb weight plus 150 pounds and the fuel tank shall be filled to any level between 90 and 100 percent of capacity. Ballast used to attain the vehicle test weight shall be firmly attached to the vehicle.
2. Fuel Tank Contents. The fuel tank shall be filled with a test fluid such as Stoddard solvent having a minimum flash point temperature of 100°F, a viscosity substantially equal to that of gasoline, and specific gravity no less than gasoline.
3. Fuel System Contents. The carburetor or fuel injection components and the fuel pump shall be filled to their normal operating level with the fluid used in the fuel tank.

7.3 BASIS FOR RECOMMENDED PERFORMANCE CRITERIA

The following discussion presents the basis for the factors specified in the recommended performance requirements.

*Federal Register, Volume 35, No. 219, Part II, Tuesday, November 10, 1970.

7.3.1 Test Vehicle. The recommended performance requirements have been specified for vehicles with a GVWR of 6,000 pounds or less because these are the only vehicles that are now required to contain fuel evaporative emission control devices. The performance requirements have been structured around the combination of fuel supply and evaporative control systems and thus might not be applicable to those vehicles which do not have the evaporative control devices. For example, the durability test has been specifically prescribed to test the evaporative control system as this program showed that the durability of the systems is questionable and that failure of these systems could increase the fire hazard during a collision. On the other hand, vehicles without evaporative control systems have atmospheric fuel tank vents which can contribute to the post-crash fire hazard, especially if the vehicle rolls on its side.

Vehicles with a GVWR rating of over 6,000 pounds should be analyzed separately to determine potential failures before specific tests are recommended for them. Although the front barrier impact test would be applicable to these vehicles, it is possible that side impact rather than rear impact tests would be more meaningful for larger vehicles.

7.3.2 Vehicle Test Weight. The vehicle test weight has been specified as the curb weight plus 150 pounds to approximate a vehicle containing a 50th percentile driver. Since a large percentage of vehicles in operation contain only one individual, this test weight should serve as a reasonable approximation of real world conditions. Although vehicles may often contain more weight than this, the difficulty of firmly attaching a large amount of ballast to the vehicle without compromising its structure precludes recommending a heavier weight. Certainly any additional weight would increase the severity (crushing energy) of the test, but it is recommended that, if an increased severity is desirable, this be accomplished by increasing the vehicle impact speed rather than specifying a heavier vehicle weight.

7.3.3 Types of Tests. As mentioned in Section 7.3.1, the durability test has been required specifically for fuel evaporative emission control systems. This program determined that some of these systems may well lose their integrity during normal operating conditions and that this loss of integrity could lead to a large quantity of fuel being lost during an accident, thus severely increasing the post-crash fire hazard. Although the reliability of the systems could be assessed on the basis of the actual system operating history in the motor vehicles in public use, several years would be necessary to accumulate statistical data upon which to base this assessment. However, the durability tests which the vehicles must pass for the emission control standards offer a rapid and convenient method of assessing the history of the control system during the vehicle's first 50,000 miles. In addition, the vehicles used for the emission control tests are

carefully maintained and any failures would be the result of design deficiencies in the system and not the result of careless or improper maintenance by the vehicle owner.

The front and rear impact tests and the roll-over tests are designed to assess the vehicle's performance during those accidents which contribute most to the incidence of fire accidents. It should be noted that a roll-over test is specified after each front and rear impact test. This is necessary because, as was shown in this program, there may be instances of component failures which do not cause fuel spillage as long as the vehicle remains in an upright position but cause massive spillage when the vehicle is rolled on its side or top. Although a roll-over test could be specified prior to impact in order to test the system design, this would be redundant as the design will be adequately tested during the roll-overs conducted after the impacts.

One other accident mode which contributes significantly to post-crash fires is an impact on the rear quarter of a vehicle containing a rear fuel tank. Although such a test might be desirable on station wagons and on side filler tanks, it is felt that the rear impact test would pick up a substantial number of failures which might occur from the rear quarter impact. In addition, it is possible that many manufacturers will have to redesign their fuel systems to meet the already proposed requirements and the redesign might simultaneously reduce the hazards from rear quarter impacts. Thus, it is recommended that no rear quarter impacts be required at this time but that, after the fuel system design modifications have been made, the possibility of requiring rear quarter impacts be reevaluated.

7.3.4 Types of Barriers. A front impact into a fixed barrier has been a standard test for investigating automobile front end collisions for many years. The fixed-barrier test offers the advantages of being highly repeatable and simple to conduct. The results between tests are readily comparable since all the kinetic energy of the impacting vehicle is converted into crushing energy. In addition, the front fixed-barrier impact realistically simulates a head-on collision between two like vehicles.

While a fixed-barrier rear end test might not seem as representative of a rear end collision as a moving-barrier test, consideration of the two types of tests leads to the conclusion that the only basic difference between a fixed-barrier and a moving-barrier test conducted at identical speeds is the degree of severity (amount of crushing energy). This may be shown mathematically if it is assumed that the vehicle and movable barrier each behave as single masses, that the collision is completely inelastic, and that the crush characteristics of the vehicle are not time dependent. For the sake of simplicity, the following model is derived assuming that the vehicle mass and the moving barrier mass are equal.

Conservation of momentum during a moving barrier test may be stated mathematically as

$$MV_B = 2MV_F \quad (3)$$

where M = mass of barrier = mass of vehicle

V_B = impact velocity of barrier

V_F = combined velocity of barrier and vehicle after impact.

Conservation of energy during a moving barrier test gives

$$\frac{1}{2} MV_B^2 = \frac{1}{2} MV_F^2 + \frac{1}{2} MV_F^2 + E_C \quad (4)$$

where E_C = crushing energy.

Solving equation 3 for V_F and substituting into equation 4 gives

$$E_C = \frac{1}{4} MV_B^2 \quad (5)$$

During a fixed barrier test, all of the energy is converted into crushing energy. Thus,

$$\frac{1}{2} MV_O^2 = E_C \quad (6)$$

where V_O = impact velocity of vehicle.

Equating 5 and 6 and solving for V_B/V_O leads to the relationship

$$\frac{V_B}{V_O} = \sqrt{2} \quad (7)$$

Thus, it may be seen that a moving-barrier test must be conducted at a higher velocity than a fixed-barrier test to attain equal crushing energies. From equation 7, it can be calculated that a 20-mph moving-barrier test is equal to a 14.1-mph fixed-barrier test, and a 30-mph moving-barrier test is equal to a 21.2-mph fixed-barrier test if the masses of the vehicle and the moving barrier are identical.

The same basic momentum and energy considerations may also be used to calculate a moving-barrier test velocity which is

equivalent to a fixed-barrier test in which the weight of the barrier and the vehicle are not identical (Ref 14). Thus,

$$\frac{V}{V_2} = \sqrt{\frac{R}{1 + R}} \quad (8)$$

where V = vehicle velocity in fixed-barrier test

V_2 = movable-barrier impact velocity

$$R = \frac{M_2}{M_1}$$

M_2 = movable-barrier mass

M_1 = vehicle mass

Calculated 4,000-pound moving-barrier test velocities which are equivalent to fixed-barrier test velocities for several different vehicle weights are shown in Table 7-I. The increasing moving-barrier velocity with increasing vehicle weight is due to the contribution of the vehicle mass to the total kinetic energy of the fixed-barrier impact.

Thus, since the severity of a moving-barrier impact may be obtained equally well with a fixed-barrier impact by adjusting the impact velocities, the choice of a moving- versus fixed-barrier test ultimately rests on which test is more repeatable and will furnish the most information. A fixed-barrier test was recommended because it is felt that the repeatability of the fixed-barrier test is more reliable since all of the kinetic energy is converted into crushing energy, while the crushing energy during a moving-barrier test depends somewhat on the velocity and trajectory of the moving barrier and the struck vehicle after the impact. In addition, the fixed-barrier test allows better camera coverage of the entire crash sequence since the vehicle remains within camera range during the entire test, while the cameras often cannot record the entire sequence of crash events during a moving-barrier test because the vehicle and barrier move out of camera range.

7.3.5 Impact Test Speeds. The fuel system integrity should be maintained up to the occupant survivability limit of the vehicle if a significant reduction in the post-crash fire hazard is to be achieved. The proposed occupant crash protection standard (Federal Register Volume 35, No. 89, May 7, 1970) specifies that occupant protection be provided in frontal fixed-barrier crashes at 30 mph. Therefore, the fuel system should also maintain its

TABLE 7-I. MOVING-BARRIER VELOCITIES EQUIVALENT TO
FIXED-BARRIER VELOCITIES

Vehicle Test Weight (lb)	Fixed Barrier Impact Velocity (mph)	Equivalent 4,000 lb Moving Barrier Velocity* (mph)
2,000	15.0	18.4
	20.0	24.5
	25.0	30.6
	30.0	36.7
	35.0	42.9
	40.0	49.0
3,000	15.0	19.8
	20.0	26.5
	25.0	33.1
	30.0	39.7
	35.0	46.3
	40.0	52.9
4,000	15.0	21.2
	20.0	28.3
	25.0	35.4
	30.0	42.4
	35.0	49.5
	40.0	56.6
5,000	15.0	22.5
	20.0	30.0
	25.0	37.5
	30.0	45.0
	35.0	52.5
	40.0	60.0

*Velocity calculated from $\frac{V}{V_2} = \sqrt{\frac{R}{1 + R}}$

where V = vehicle velocity in fixed-barrier test

V_2 = movable-barrier impact velocity

$$R = \frac{M_2}{M_1}$$

M_2 = movable-barrier mass

M_1 - vehicle mass

integrity in a front barrier impact at this speed. This requirement should pose no difficulty for near term implementation as many vehicles meet this requirement now. Vehicles that do not meet it should require only minor fuel system modifications to be able to pass the test. It is recommended that the front barrier impact speed requirement for fuel system integrity be raised as the occupant crash protection impact speed is raised. This will prevent a vehicle occupant who has survived a crash from perishing in a subsequent post-crash fire.

At the present time there is no occupant crash protection criteria for rear end collisions. However, Severy, et al, (Ref 5), showed that a well designed safety seat would protect most passengers from sustaining significant rear end collision injuries up to 55 mph. The results of Severy's study plus the occurrence of many high-speed rear end collisions on today's freeways and the increased incidence of post-crash fires in severe accidents dictates that the fuel system should retain its integrity at collision speeds approaching, if not equivalent to, 55 mph.

The determination of a barrier impact speed equivalent to a 55-mph, vehicle-to-vehicle, rear end collision must take into account the difference in stiffness between the front and rear end of the vehicles. In general, the front end of a vehicle is stiffer and will not crush as much as the rear end does. However, the results of this program (Section 5.4.2) showed that the relative stiffness of the front and rear ends of a vehicle varies considerably with the vehicle construction and no definite stiffness ratio may be assigned which is valid for all vehicles. Thus, the barrier impact speed equivalent to a vehicle-to-vehicle collision speed must be calculated using maximum and minimum limits.

As a maximum limit, it may be assumed that the striking vehicle does not crush at all and therefore does not absorb any of the crushing energy. In this case, the striking vehicle behaves as a moving barrier and calculations using equation 7 show that a 30-mph fixed-barrier impact would be equivalent to a 42.5 mph rear end collision between two vehicles of equal weight.

As a minimum limit, it may be assumed that the striking vehicle crushes as much as the struck vehicle and therefore absorbs half of the crushing energy. Should this happen, the following energy considerations will apply:

The total crushing energy available during a vehicle-to-vehicle collision may be derived in the same manner as equation 5 and may be stated as

$$E_c = \frac{1}{4} MV^2 \quad (9)$$

where E_c = total crushing energy

M = mass of striking vehicle = mass of struck vehicle

V = impact velocity of striking vehicle.

However, since the struck vehicle absorbs only half the crushing energy, the energy absorbed by the struck vehicle is

$$E_{c_1} = \frac{1}{8} MV^2 \quad (10)$$

All of the energy is converted into crushing energy during a fixed-barrier test and thus

$$E_{c_1} = \frac{1}{2} MV_o^2 \quad (11)$$

where V_o = impact velocity of vehicle.

Equating 10 and 11 and solving for V/V_o leads to the relationship

$$\frac{V}{V_o} = 2 \quad (12)$$

Equation 12 shows that the car-to-car collision velocity will be twice the barrier velocity, or 60-mph car-to-car for a 30-mph fixed-barrier test.

The vast majority of rear end collisions will involve striking vehicles falling somewhere between the two limits of absorbing no crushing energy and absorbing half the crushing energy. Thus, the 30-mph speed for the rear end fixed-barrier test is recommended as a reasonable and desirable test speed. However, in view of the rear end barrier tests conducted during this program, the 30-mph speed must be considered a long term goal as major fuel system design changes will probably have to be made to most vehicles now being manufactured to enable them to meet this requirement. Therefore, a near term impact speed requirement of 20 mph is recommended. Although several vehicles tested at 20 mph during this program could not meet the requirement, minor modifications to most of the vehicles now in use should enable them to meet the 20-mph fixed-barrier test speed.

In the event that a moving-barrier test is instituted for the rear impact test, it is strongly recommended that the moving-barrier test be run at speeds equivalent to 20 and 30 mph fixed-barrier tests to insure fuel system integrity during fairly severe accidents.

7.3.6 Roll-Over Tests. The time required to rotate the vehicle through a 90-degree increment should be less than 1 minute to realistically simulate an actual roll-over accident. This time limit is necessary to insure that any check valves which might be used in the system to prevent fuel spillage will actuate during this time period.

The 5-minute time limit at each successive position will assure that any fuel spillage from any part of the system will be detected. This is especially important since the crushing of the vehicle structure during an impact test can often obscure fuel system damage which leads to fuel spillage. Therefore, time must be allowed for any spillage to run through the structure to a position where it is readily visible.

7.3.7 Fuel Spillage Limit. Although the optimum requirement would be absolutely no spillage from the fuel system during these tests, this is considered technically infeasible in those areas where check valves might be required to prevent spillage, i.e., around the filler cap and from the carburetor. Any type of check or anti-surge valve would allow some fuel spillage during the process of closure. However, if the amount of the spillage is limited and controlled, the likelihood of the small amount of fuel spillage allowed in the collision test requirements (1 ounce or less) should present no undue fire hazards. However, this fuel spillage should not be allowed to exist in a vapor form which can travel long distances to reach ignition sources and which is much more easily ignited than liquid fuel. Thus, the requirement for no visible spray from the filler cap during the barrier impacts. The requirement that no surge from the carburetor impinge on any part of the engine compartment prohibits not only vapor spray but also liquid fuel from being discharged into the engine compartment with its multitude of possible ignition sources.

The requirement that no more than 1 ounce total fuel spillage be allowed from the filler during each 90-degree increment during the roll-over tests is also incorporated to allow for a minor amount of fuel spillage occurring from any check valve which might be present. The long term requirements for the carburetor also make this same allowance. However, because of the difficulties in redesigning the carburetor and adjusting the resulting effects on engine performance, a near term requirement has been allowed in which the float bowl contents may spill but no further spillage is allowed from the carburetor.

It is felt that it is technically feasible and desirable that no fuel spill from any other part of the fuel system during impact or roll-over. It is also deemed technically feasible and imperative that there be no post-impact fuel spillage from any source. This requirement prevents fuel from puddling anywhere near the automobile after it has come to rest. Fuel leakage

after impact could be ignited by an outside source which could not be controlled. In addition, fuel spillage on the hot exhaust components or even on hot pavement could lead to vaporization of the fuel into a highly volatile mixture. Although the amount of fuel spilled might not be large, the ignition of even a small amount of fuel can lead to a catastrophic fire which rapidly spreads to other parts of the vehicle.

8. RECOMMENDATIONS FOR FURTHER INVESTIGATION

This program revealed several areas requiring further investigation and/or initial investigation. The following recommendations define these areas and briefly describe the necessary effort involved in each.

PRIORITY 1: ACCELERATED ENVIRONMENTAL TESTING OF FUEL AND EVAPORATIVE EMISSION CONTROL SYSTEM COMPONENTS

The effects of long term vehicle use on the fuel and evaporative control system components could not be adequately assessed during this program. However, several instances of actual and potential component failures associated with wear and/or aging were noted in the vehicles which were examined. Failure of some of these components could lead to major fuel spillage during an accident. Therefore, data should be obtained as soon as possible on the effects of long term aging, vibration, etc., on the system components. These data could be obtained by laboratory tests conducted under accelerated environmental conditions. In addition, vehicles which are subjected to the 50,000 mile durability tests conducted for emission control standards should be carefully monitored for any evidence of actual or potential component failures.

PRIORITY 2: CONTINUING ANALYSIS OF FUEL AND EVAPORATIVE EMISSION CONTROL SYSTEMS IN VEHICLES WITH A GVWR OF 6,000 POUNDS OR LESS

The majority of the fuel system fire hazards uncovered during this program were associated with component and system location with respect to the vehicle structure and other vehicle components, although a few fire hazards were the result of the fuel or evaporative emission control system design. In either case, the hazards could not have been uncovered without detailed inspection and analysis of the vehicle itself. The design changes in the evaporative control systems in many vehicles between the 1970 and 1971 models resulted in significant reductions or, in some cases, increases in the fire hazards of these vehicles. Further changes have been made between some 1971 and 1972 model vehicles. It is therefore recommended that a continuing program of vehicle inspection and analysis, based on the results of this study, be conducted on all new model year vehicles under 6,000 pounds GVWR.

PRIORITY 3: ANALYSIS OF FUEL SYSTEMS IN VEHICLES WITH A GVWR OF 6,000 POUNDS OR MORE

The frequency of fire accidents occurring with trucks and buses weighing more than 6,000 pounds approximates that found with the lighter vehicles. The large loss of life that often accompanies such an accident dictates that these vehicles have as safe a fuel system as possible and NHTSA has therefore recommended including

larger vehicles in the proposed Fuel System Integrity standard. The major differences in the fuel systems of the larger and smaller vehicles, however, warrants a program of detailed fuel system analyses and vehicle inspections to determine probable system failure modes in the larger vehicles. With these data, optimum testing procedures could be developed to insure adequate fuel system safety standards for vehicles with a GVWR of 6,000 pounds or more.

PRIORITY 4: DESIGN AND TESTING OF CRASHWORTHY AUTOMOTIVE FUEL SYSTEMS

The results of this program have shown that the fuel system integrity in current model vehicles is inadequate to protect the vehicle occupants from the threat of a post-crash fire in moderate to severe accidents. However, the knowledge and techniques necessary to improve the crashworthiness of automotive fuel systems are available. Many relatively minor modifications would significantly increase the integrity of the fuel systems during moderately severe accidents. Protection during more severe accidents could be provided by using techniques currently employed in crashworthy aircraft fuel systems. Both levels of modification should be investigated to determine the upper limit of fuel system integrity which would be provided by each system. The systems should be designed, installed, and subjected to full-scale crash tests to demonstrate the feasibility of providing a high level of fuel system integrity with an attendant reduction in the post-crash fire hazard.

PRIORITY 5: GENERATION OF FIRE HAZARD STATISTICAL DATA

Statistical data on automotive post-crash fires is extremely limited, although these data would be very helpful in determining the exact extent of the fire threat and would help delineate particularly hazardous fuel system configurations. The proposed establishment of a uniform, comprehensive motor vehicle traffic accident investigation program in each state offers a feasible method of obtaining such data. A section specifically designated for fire accidents should be included in the investigation program and information obtained therefrom should be compiled into statistical data suitable for analysis.

9. REFERENCES

1. INVESTIGATION OF MOTOR VEHICLE PERFORMANCE STANDARDS FOR FUEL TANK PROTECTION, Phase I Final Report, Fairchild Hiller, Farmingdale, New York, September 1967.
2. Robinson, S. J., OBSERVATIONS ON FIRE IN AUTOMOBILE ACCIDENTS, CAL Report No. VJ-1823-R14, Cornell Aeronautical Laboratory, Inc., Buffalo, New York, February 1965.
3. Moore, J. O., and Negri, D. B., FIRE IN AUTOMOBILE ACCIDENTS, Research Report 1969-2, New York State Department of Motor Vehicles, State of New York, October 1969.
4. Brayman, A. F., Jr., IMPACT INTRUSION CHARACTERISTICS OF FUEL SYSTEMS, CAL No. VJ-2839-K, Cornell Aeronautical Laboratory, Inc., National Highway Safety Bureau, Federal Highway Administration, U. S. Department of Transportation, Washington, D. C. 20591, April 1970, DOT HS 800 296.
5. Severy, D. M., Brink, H. M., and Baird, J. D., BACKREST AND HEAD RESTRAINT DESIGN FOR REAR-END COLLISION PROTECTION, Paper presented at Automotive Engineering Congress, Detroit, Michigan, January 8-12, 1968, SAE Paper 680079.
6. Severy, D. M., Brink, H. M., and Baird, J. D., VEHICLE DESIGN FOR PASSENGER PROTECTION FROM HIGH-SPEED REAR-END COLLISIONS, Twelfth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, New York, October 1968.
7. FUEL TANK PROTECTION, Volume I, Fairchild Hiller, Farmingdale, New York, PB-191 148.
8. Robertson, S. H., A NEW LOOK AT FUEL SYSTEM DESIGN CRITERIA, Tenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, New York, November 1966.
9. Locati, L., and Franchini, E., INDAGINE SULL' INCENDIO DI VETTURE CAUSATO DA COLLISIONE (CAR CRASH-FIRE INVESTIGATION), Paper presented at 11th Fisita Congress, Munich, June 1966.
10. Gatlin, C. I., and Johnson, N. B., PREVENTION OF ELECTRICAL SYSTEMS IGNITION OF AUTOMOTIVE CRASH FIRE, AvSER 2310/20-70-7, Dynamic Science, National Highway Traffic Safety Administration, U. S. Department of Transportation, Washington, D. C. 20591, March 1970, DOT HS 800 392.

11. Sarto, J. O., Fagley, W. D., and Hunter, W. A., CHRYSLER EVAPORATION CONTROL SYSTEM, THE VAPOR SAVER FOR 1970, Paper presented at Automotive Engineering Congress, Detroit, Michigan, January 12-16, 1970, SAE Paper 700150.
12. CRASH SURVIVAL DESIGN GUIDE, USAAMRDL Technical Report 71-22, Dynamic Science, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, October 1971.
13. Robertson, S. H., DEVELOPMENT OF A CRASH-RESISTANT FLAMMABLE FLUIDS SYSTEM FOR THE UH-1A HELICOPTER, USAAVLABS Technical Report 68-82, Dynamic Science, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, January 1969.
14. Berton, R. J. and MacLean, R. B., POTENTIAL APPLICATIONS FOR THE MOVABLE BARRIER IN VEHICLE CRASH TESTING, Paper presented at 1970 International Automobile Safety Conference, Detroit, Michigan, May 13-15, 1970, SAE Paper 700408.

APPENDIX A

EVAPORATIVE EMISSION CONTROL SYSTEM EVALUATION SHEET - NON-CRASHED VEHICLE

Date _____ Photo Nos. _____

Manufacturer _____

Body Style _____

Registered Owner _____

Address _____

Odometer Mileage _____

Vehicle I.D. No.

--	--	--	--	--	--	--	--

Body I.D. No.

--	--	--	--	--	--	--	--

1. Description of ECS System.	
2. Assessment of possibility for mechanical chafing.	
3. Assessment of possible damage due to excessive heating from the exhaust system.	

8. Evaluation of design as to: a. Structural strength	
b. Effect of component malfunction on total system (as to safety hazard)	
c. Effect of other system malfunction on component (as to safety hazard)	
9. Evaluate possible effect of maintenance errors or omissions on component and system (as to safety hazard)	
10. Additional Comments	

COMPONENT EVALUATION SHEET 1

Vehicle Make and Body Style _____

VIN _____

	Part Number	Visual Description	Susceptibility to Mechanical Chafing	Deterioration Due to Aging	Exposure to High Temperature
Filler Cap					
Fuel Tank					
Vapor Lines, FT-LVS					
Liquid-Vapor Separator					
Vapor Line, LVS-Storage (Routing, etc.)					
Vent Valve					
Canister					
Vapor Line, Fuel Bowl to Storage					
Purge Line					
Carburetor					
Pressure Relief System					
Miscellaneous					

COMPONENT EVALUATION SHEET 2

Vehicle Make and Body Style _____ VIN _____

	Possible Effect on Motor Performance	Effect of Improper Maintenance	Probable Owner Modifications	Comments
Filler Cap				
Fuel Tank				
Vapor Lines FT-LVS				
Liquid-Vapor Separator				
Vapor Line LVS-Storage (Routing, etc.)				
Vent Valve				
Canister				
Vapor Line, Fuel Bowl to Storage				
Purge Line				
Carburetor				
Pressure Relief System				
Miscellaneous				

Will fuel surge in tank produce spillage through the filler cap?	
Can fuel spill (or leak) from the system into the trunk compartment?	
Under what conditions can vapor accumulate in the trunk?	
Can vapor condensation occur beyond the liquid-vapor separator?	
Is the fuel tank level below the bottom of the vapor storage reservoir at all normal attitudes of the auto?	
Will liquid usually be present in the liquid-vapor separator? Under what conditions? Can lines between tank and separator easily be damaged in normal use? Under crash conditions?	
If fuel tank is compressed in a crash, how far would fuel be forced into the ECS system?	

APPENDIX B

EVAPORATIVE EMISSION CONTROL SYSTEM
EVALUATION SHEET - CRASHED VEHICLE

Date _____ Photo Nos. _____

Manufacturer _____

Body Style _____

Model Year _____

<u>Type of Accident and Relative Severity</u> (Direction of impact; minor, moderate, severe)	
<u>General Appearance of Vehicle</u> (Areas damaged, extent of damage, evidence of fire, evidence of occupant entrapment)	
<u>Interaction of Vehicle Frame or Body Structure with Fuel, Electrical, Exhaust Systems</u> (location, type of damage caused)	

Describe condition of following systems. Include failure locations and modes (e.g., breakage of attachments, direct impact, secondary impact, etc.)

Fuel System
(leakage?)

Evaporative
Emission Con-
trol System

Electrical
System

Exhaust
System

List interactions between fuel, electrical, exhaust systems.	
Additional Comments	

APPENDIX C

EXTREME TEMPERATURE TESTS

C.1 TEST OBJECTIVE

The objective of these tests was to identify any condition of the fuel system (including the evaporative emission control system) which could constitute a safety hazard when the vehicle is in use in geographical locations having high daytime temperatures.

C.2 TEST CONDITIONS

Palm Springs, California was chosen as the test location because 1970 vehicles with evaporative emission control systems were available from rental agencies in this region and Weather Bureau data show an average daily maximum temperature of 106.3°F during September. Maximum temperature on the day of the test (September 4, 1970) was 101°F.

A search was made at Palm Springs for a test site meeting the following requirements:

- Maximum daytime exposure to the sun.
- Adequate space for four vehicles with approximately the same slope for each.
- Reasonably close to a filling station to minimize fuel consumption while moving the vehicles to the test site.
- Moderately sloped, typifying a condition which might reasonably be found in normal use of the vehicle.

A parking lot location was chosen which met all of the foregoing requirements including a slope of approximately 12 percent.

C.3 TEST VEHICLES

Four 1970 cars representing various evaporative emission control systems were obtained from rental agencies for this test:

1. Ford Mustang
2. Chevrolet Impala
3. American Motors Rebel
4. Volkswagen Sedan ("Beetle")

C.4 TEST PROCEDURE

The automobiles were driven approximately one-half mile to a filling station, filled to their spill point, and then driven back to the test site. Iron-constantan thermocouples were attached to the fuel tanks to obtain approximate fuel temperatures without disturbing the fuel or evaporative emission control systems.

The vehicles were parked at 30-degree angles on the 12-percent slope. The Volkswagen was parked front-end-up and the others were all backed onto the slope. In this position, the right wheels were approximately 2.5 inches above the left wheels and the front wheels approximately 12 inches below the rear wheels for the large vehicles. For the Volkswagen, these dimensions were all slightly less and the directional sense was reversed since it was front-end-up on the slope.

Air and fuel tank temperatures were recorded throughout the day. Approximately one-half hour after the maximum fuel tank temperatures were attained, all the vehicles were turned around on the slope and parked in the opposite direction for one hour.

The fuel and evaporative control systems were observed throughout the test for any fuel leakage.

C.5 TEST RESULTS

The fuel tank and ambient air temperatures are shown in Table C-I. The peak ambient air temperature (97°F) was reached shortly after the test began. This is below the official high reported for the day of 101°F that occurred around noon. Fuel tank temperatures ranged from 77°F to 112°F.

The Volkswagen had been obtained the day before the test and the low (62°F) nighttime temperature cooled the gasoline in the Volkswagen tank (which had been about half full). Accordingly, after filling the next morning, the average fuel tank temperature for it was less than for the other vehicles which had been completely filled from the underground reservoir (temperature = 86.9°F) on the morning of the test.

No fuel leakage was noted for any of the vehicles in the first test position.

A subjective evaluation of pressure buildup in the fuel tanks was made by removing the filler caps. There was no noticeable pressure buildup in either the Volkswagen or the Impala. The Mustang registered a slight positive pressure. When the filler cap on the Rebel was removed, fuel poured out at such a rate that approximately 1 quart was lost before the cap could be replaced. Evidently, when parked in this position, fuel closes

TABLE C-I. EXTREME TEMPERATURE TEST DATA					
Time of Day	Ambient Temperature (F°)	Fuel Tank Temperature (°F)			
		Volkswagen	Rebel	Mustang	Impala
7:10 a.m.	75	77 (start)*			
8:10 a.m.	97			91 (start)	
9:20 a.m.			92 (start)		
10:25 a.m.	97	105	101		94 (start)
10:45 a.m.					102
11:05 a.m.	92	103	103		
12:50 p.m.		107			
1:10 p.m.	97		102		112
3:00 p.m.	97	106	99	105	103
Temperature of gasoline from underground storage reservoir was 86.9°F.					
*The VW tank was half full during the night and topped off in the morning. The low starting temperature reflects the effect of the low night time (62°F) temperature in cooling gasoline contained in the tank during the night.					

the Rebel check valve so that vapors cannot escape to the crankcase. The second avenue of escape, the pressure-vacuum filler cap, was also unavailable since fuel was backed up against it.

All the vehicles were then turned around on the slope and parked in the opposite direction for an hour. Again, no leakage was detected at any point in the fuel systems.

Pressure buildup was checked again in all the vehicles while in the reversed position. No buildup was noted in the Rebel at this time since the reverse position favored proper operation of the pressure relief system. Results essentially similar to the first check were noted on the remaining three vehicles.

APPENDIX D

PITCH TESTS

D.1 TEST OBJECTIVE

The objective of these tests was to assess the possibility of spillage occurring from the fuel system (including the evaporative emission control devices) when either the front end or rear end of the vehicle is elevated. The test conditions were designed to simulate pitch attitudes which may be encountered during normal driving conditions as well as more severe attitudes which could be encountered during or following an accident.

D.2 TEST VEHICLES

The tests were conducted on five 1971 cars:

1. General Motors Chevelle
2. Ford Mustang
3. Plymouth Satellite
4. Volkswagen "Super Beetle"
5. American Motors Hornet

All of these vehicles, with the exception of the Volkswagen, were obtained from rental agencies just prior to the test. The Volkswagen was obtained from a private owner.

D.3 TEST PROCEDURE

The vehicle fuel tank was filled to its spill point with gasoline and then 10 percent of the rated fuel tank capacity was removed. This resulted in the fuel tank containing 90-91 percent of its capacity.

The test vehicle was then secured on a steel rocker platform centered between the uprights of a drop tower. One end of the platform was raised in 15-degree increments to a maximum of 60 degrees with the drop tower hoisting mechanism. Fuel spillage, if any, at each 15-degree elevation increment was measured and recorded photographically and by notation. The platform was then lowered to a level position and the procedure repeated with the opposite end being elevated. Figure D-1 shows maximum 60-degree positions for both front and rear end elevations.



Figure D-1. Maximum 60-Degree Pitch Attitudes.

D.4 TEST RESULTS

1. Chevelle Malibu: There was no fuel spillage at any angle when the front end was raised. No spillage occurred when the rear end was raised to 30 degrees. However, approximately 20 seconds after the rear end was raised to 45 degrees, fuel began running from the bottom of the carbon canister at a rate of 52 ounces per minute. This flow rate continued until approximately 3 gallons of fuel was lost, at which time the spillage stopped.

The fuel spillage occurred as the liquid-vapor separator, which is located above the forward end of the fuel tank (behind the rear seat), filled with fuel and allowed the fuel to flow through the vapor line to the canister which is open at the bottom. As soon as the fuel level in the tank dropped below the top of the standpipe, fuel spillage ceased.

2. Ford Mustang: No fuel spillage occurred at any of the test attitudes.
3. Plymouth Satellite: No spillage occurred when the front end was raised to 45 degrees. At 60 degrees, a slight amount of leakage was noted around the filler cap but was too slight to measure. No spillage occurred when the rear end was raised to 45 degrees. At 60 degrees, a minor amount of spillage (0.06 oz/min) occurred from the carburetor.
4. Volkswagen "Super Beetle": There was no fuel spillage when the rear end of the vehicle was raised to the maximum of 60 degrees. No spillage occurred when the front end was raised to 30 degrees. However, when the front end was raised to 45 degrees, fuel began leaking from the filler cap at a rate of 1 oz/min. This flow rate continued as long as the vehicle was elevated at or above this angle.
5. American Motors Hornet: No spillage occurred when the front end was raised to 30 degrees. At 45 degrees, a minor amount of spillage (0.2 oz/min) occurred from the filler cap. This rate increased to 0.7 oz/min when the vehicle was raised to 60 degrees. The fluid head at this time was 35 inches, corresponding to approximately 1 psi pressure.

There was no fuel spillage when the rear end was raised to 30 degrees. However, at 45 degrees, major spillage (approximately 15 oz/min) occurred from the vapor hose leading from the front left corner of the fuel tank to the liquid check valve. The spillage rate from this

source increased to approximately 25 oz/min at 60 degrees.

An inspection of the rubber vapor hose showed that it had been burned almost through where it had come in contact with the tail pipe, as shown in Figure 5-4. (The odometer of the vehicle registered 4,281 miles at the time of the test.) Raising the rear end of the vehicle allowed fuel to enter the hose and consequently flow from the damaged line.

APPENDIX E

ROLL-OVER TESTS

E.1 TEST OBJECTIVE

The objective of these tests was to assess the probability of fuel spillage occurring during a roll-over accident. Test conditions were designed to provide support data for the proposed amendment to FMVSS 301, which specifies no fuel leakage during a roll-over test performed after the vehicle has impacted a fixed collision barrier.

E.2 TEST VEHICLES

The roll-over tests were conducted on five vehicles which had been previously subjected to 30 mph front-end barrier crashes under other NHTSA contracts:

1. 1970 Chevelle Malibu
2. 1970 American Motors Ambassador
3. 1970 Toyota Corolla
4. 1971 Ford Pinto
5. 1971 Dodge Polara Station Wagon

E.3 TEST PROCEDURE

The carburetor float bowls were filled and the fuel tanks were filled to 90-percent capacity with Stoddard solvent. The vehicles were then rotated in 90-degree increments around their longitudinal axis, coming to rest on their left side, top, and right side successively. Fuel spillage, if any, at each test attitude was measured and recorded photographically and by notation.

E.4 TEST RESULTS

1. Chevelle Malibu: The only spillage during this test came from the carburetor. As soon as the vehicle was rotated onto its side, the entire contents of the carburetor float bowl spilled.
2. American Motors Ambassador: The main source of spillage during this test was the fuel pump inlet fitting which had been broken during the barrier test. A continual stream of fuel (44 oz/min) ran from the broken fuel line fitting as soon as the vehicle was rotated onto its left side. Spillage continued at the same rate when the vehicle was inverted. The natural resting position of the

vehicle on its top placed the fuel tank above the broken fitting (Figure 5-59); thus, the complete contents of the fuel tank would have been spilled if the leakage had been allowed to continue. No fuel was spilled from the line with the vehicle on its right side because of the routing of the fuel line on the left side of the car.

Several ounces of fuel were also spilled from around the filler cap when the vehicle was on its left side. (The filler is located in the left rear quarter panel.) The fluid head at this time was 50 inches, or approximately 1.5 psi. The pressure relief valve in the filler cap is designed to open at a pressure of 0.5 - 1.0 psi.

Spillage also occurred from the carburetor when the vehicle was rotated onto its side and top. By the end of the test, all of the fuel in the carburetor float bowl had been spilled.

3. Toyota Corolla: No spillage occurred from the fuel tank or lines in any of the roll-over attitudes. Leakage from the carburetor could not be determined since the carburetor base-to-manifold mounting had been broken during the barrier crash and the carburetor could not be replaced.
4. Ford Pinto: Approximately 0.5 oz/min of fuel was spilled from the filler cap when the vehicle was resting on its left side. (The filler is located in the left rear quarter panel.) The fluid head at this time was 34 inches, corresponding to approximately 1 psi pressure.

Some spillage occurred from the carburetor as the vehicle was rotated onto its top, but more spillage occurred from the carburetor float bowl with the vehicle on its right side. This spillage came from the decelerator valve-carburetor hose which had been partially severed during the front-end impact. The spillage rate from this source was 0.2 oz/min.

5. Dodge Polara Station Wagon: The main source of spillage was the carburetor which spilled the contents of the float bowl as the vehicle was rotated onto its top. A slight amount of spillage (0.03 oz/min) was also observed from the filler cap when the vehicle was on its top. No spillage occurred with the vehicle on its left or right side.

APPENDIX F

COMPONENT AND SUBSYSTEM TESTS

F.1 TEST OBJECTIVE

The objective of this series of dynamic tests was to assess the integrity of automotive fuel evaporative emission control subsystems, components, and their attachments when subjected to typical automobile crash accelerations. The test conditions were designed to simulate the crash pulses imparted to vehicles during 30- and 45-mph barrier impacts.

F.2 TEST ITEMS

Complete fuel evaporative emission control subsystems and selected individual components from these systems comprised the test items for this test series.

The subsystems tested were those of the 1970 General Motors Chevelle, Ford Mustang, Volkswagen Sedan, and Toyota Corolla. The specific test items making up the subsystems were as follows:

Chevelle

Fuel Tank
Filler Neck and Cap
Liquid-Vapor Separator
Carbon Canister
Carburetor
Air Cleaner
Lines and Hoses

Mustang

Fuel Tank
Filler Neck and Cap
Vent Connector Assembly
Liquid-Vapor Separator
Three-Way Control Valve
Carbon Canister
Carburetor
Air Cleaner
Lines and Hoses

Volkswagen Sedan

Fuel Tank
Filler Neck and Cap
Expansion Chamber
Carbon Canister
Carburetor
Air Cleaner
Lines and Hoses

Toyota Corolla

Fuel Tank
Filler Neck and Cap
Air Filter
Thermal Expansion Tank
Fuel Vapor Storage Case
Carburetor
Air Cleaner
Connecting Lines and Hoses

The individual components from the above systems which were subjected to further tests included:

Toyota: Vapor Storage Case, Expansion Tank, and Fuel Tank With Filler and Cap

Volkswagen: Carbon Canister and Expansion Tank

Mustang: Carbon Canister and Liquid-Vapor Separator With Vent Connector Assembly

Chevelle: Carbon Canister and Liquid-Vapor Separator

Toyota, Mustang, and Chevelle: Carburetors

All of the components with the exception of the Toyota expansion, vapor storage, and fuel tanks were purchased new specifically for these tests. The Toyota tanks were obtained from a Corolla which had been previously front-end barrier crashed after examination disclosed that the tanks were not damaged.

F.3 TEST PROCEDURE

The test program consisted of a series of ten dynamic tests conducted on the drop tower/sled facility illustrated in Figure F-1. Nine tests involved sled runs using both large and small sleds, while the tenth was a drop test using a drop cage and tower. The test matrix is shown in Table F-I.

All components were installed in simulated vehicle structure with attachments identical to those used in the vehicle. The Mustang and Volkswagen subsystems were installed in actual vehicle structures obtained from wrecking yards. The Chevelle fuel tank was fastened to the underfloor structure of a wrecked Chevelle which was supported in a steel framework to simulate the actual vehicle installation. The Toyota subsystem was also mounted in a steel framework simulating the vehicle structure.

Wherever space on the sled permitted, the subsystem components were installed in the same relationship to each other as occurs in the vehicle. Fuel tanks were filled to 90-percent capacity with Stoddard Type II solvent. The orientation of the components on the sled was varied to simulate front, rear, and side impact collisions. Figures F-2 through F-11 show the setups for each test.

The desired crash pulses for the tests were based on acceleration-time histories of barrier impacts conducted during other NHTSA programs. These data show that frame-mounted components can be expected to experience peak decelerations of 30 to 50G with pulse durations around 100 msec during 30-mph frontal impacts with correspondingly higher decelerations at higher velocities.

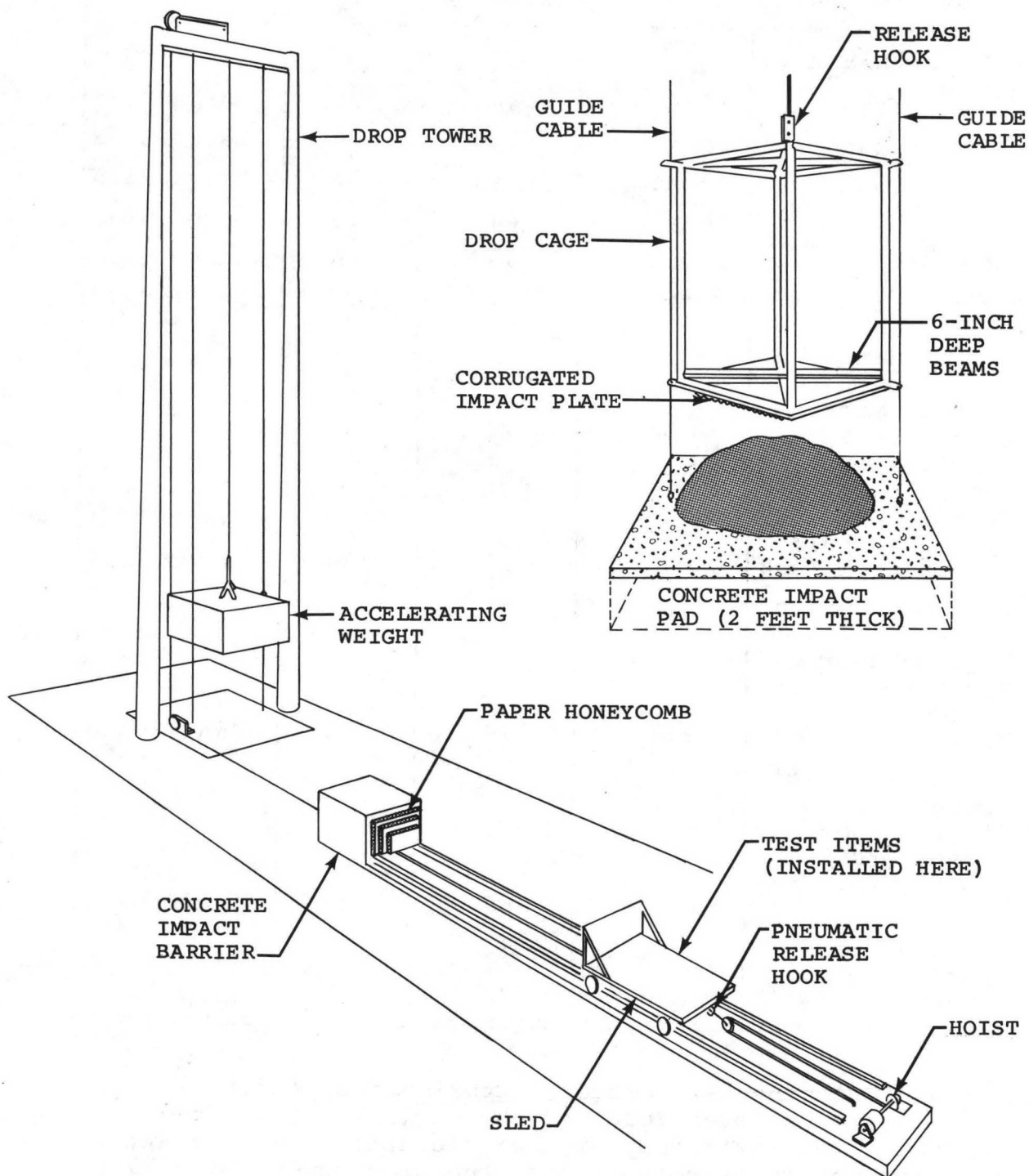


Figure F-1. Drop Tower/Horizontal Sled Facility.

TABLE F-I. COMPONENT AND SUBSYSTEM TEST MATRIX

Test No.	Test Items(s)	Direction of Impact	Desired Impact Velocity		Facility Used
			(ft/sec)	(mph)	
	<u>Subsystems</u>				
1	Ford Mustang	Front	44	30	Large Sled
2	Ford Mustang	Rear	44	30	Large Sled
3	G.M. Chevelle	Front	44	30	Large Sled
4	G.M. Chevelle	Rear	44	30	Large Sled
5	VW Sedan	Front	44	30	Large Sled
6	Toyota Corolla	Rear	44	30	Large Sled
	<u>Components</u>				
7	4 Vapor Storage Containers; 4 Liquid-Vapor Separators (Ford, G.M., V.W., Toyota); Toyota Fuel Tank	Side	44	30	Large Sled
8	3 Vapor Storage Containers; 3 Liquid-Vapor Separators (Ford, G.M., V.W.)	Front	66	45	Small Sled
9	3 Vapor Storage Containers; 3 Liquid-Vapor Separators (Ford, G.M., V.W.)	Rear	66	45	Small Sled
10	3 Carburetors (Ford, G.M., Toyota)	Front	44	30	Drop Tower

Engine-mounted components, however, experience considerably higher decelerations (over 200G) if the engine contacts the struck object. This extremely high deceleration was programmed for the carburetor tests conducted on the drop tower (Test 10).

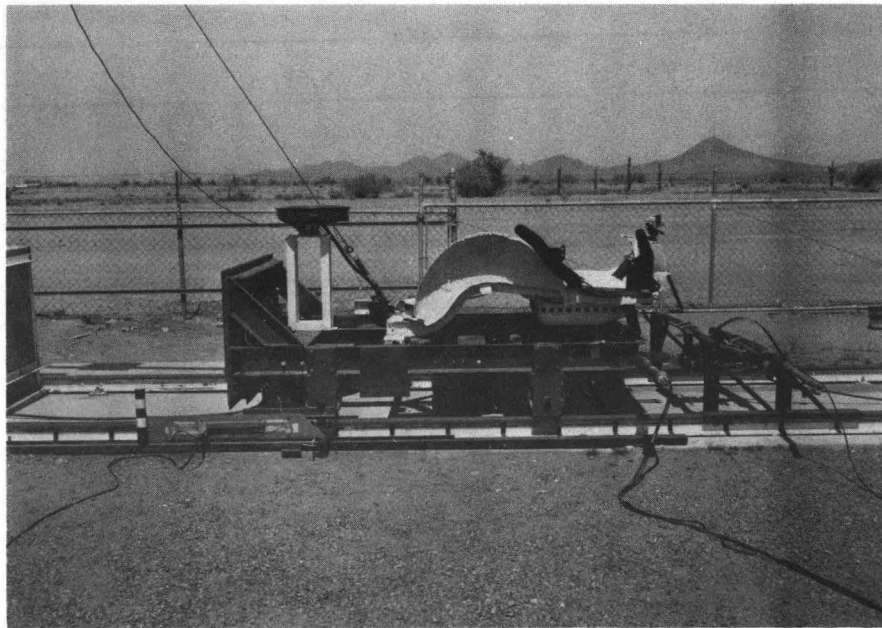


Figure F-2. Test Setup for Test 1
(Mustang Subsystem).

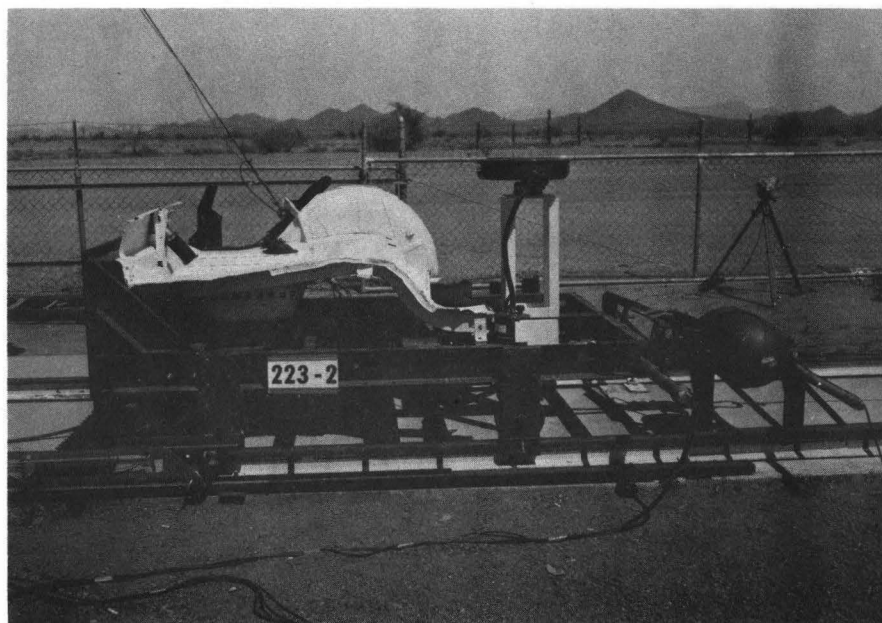


Figure F-3. Test Setup for Test 2
(Mustang Subsystem).

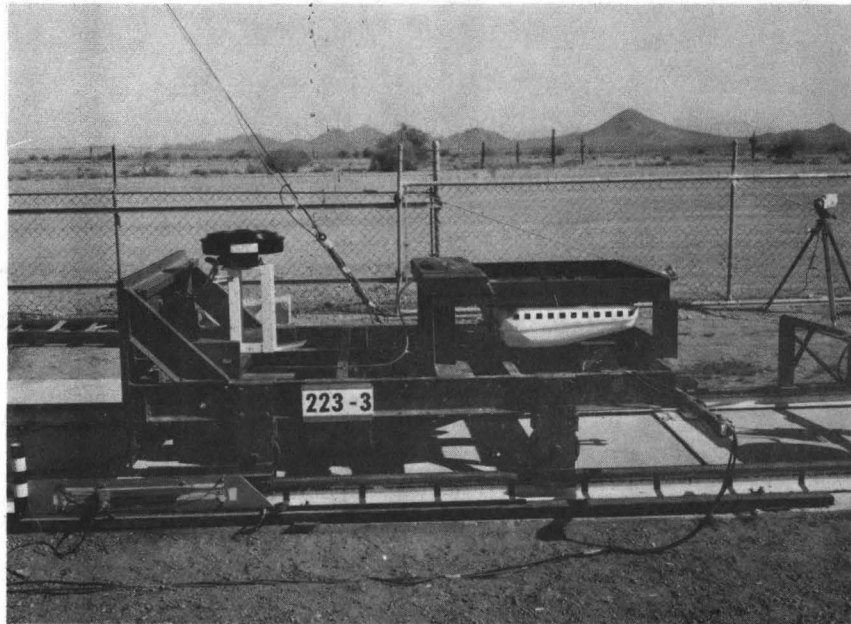


Figure F-4. Test Setup for Test 3
(Chevelle Subsystem).

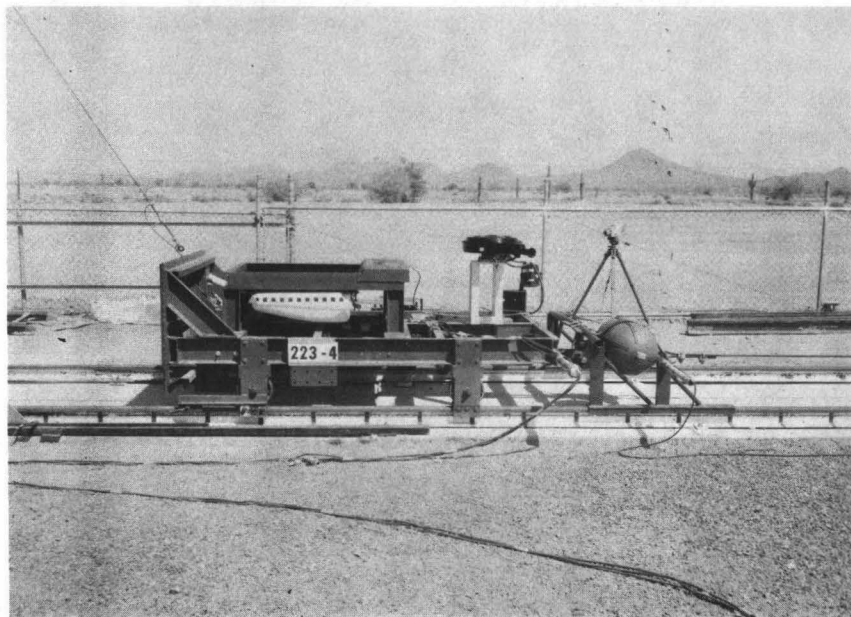


Figure F-5. Test Setup for Test 4
(Chevelle Subsystem).

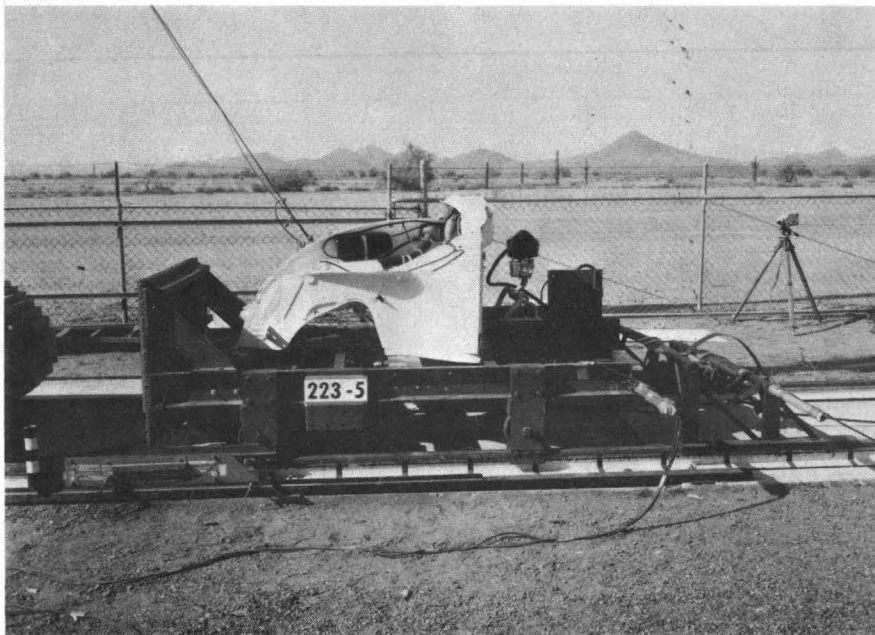


Figure F-6. Test Setup for Test 5
(Volkswagen Subsystem).

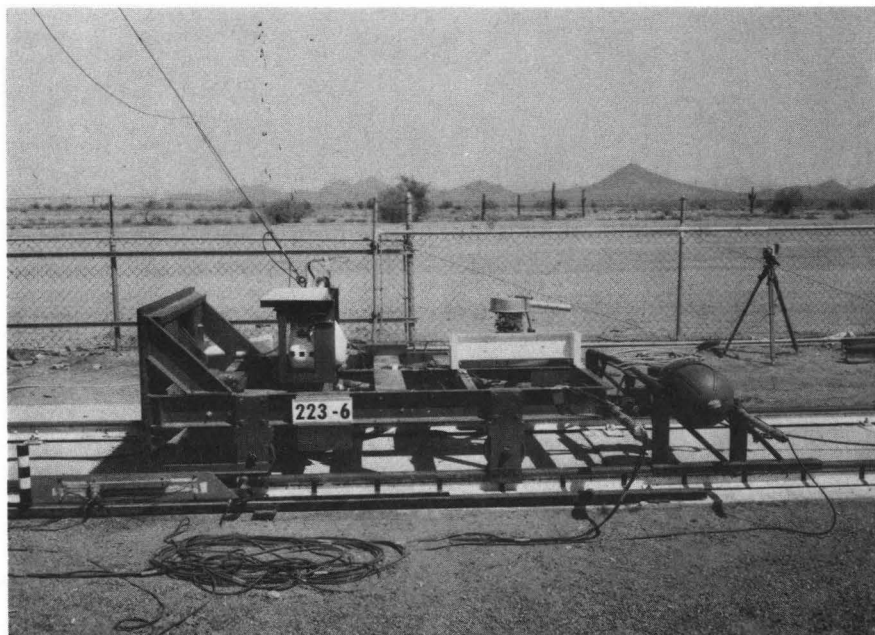


Figure F-7. Test Setup for Test 6
(Toyota Subsystem).

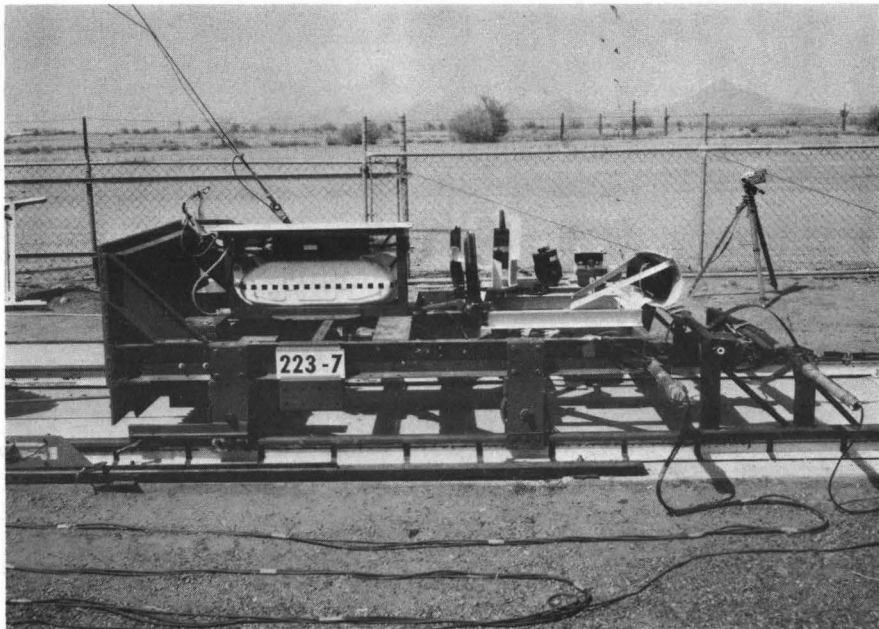


Figure F-8. Test Setup for Test 7 (four vapor storage containers, four liquid-vapor separators, and one fuel tank).

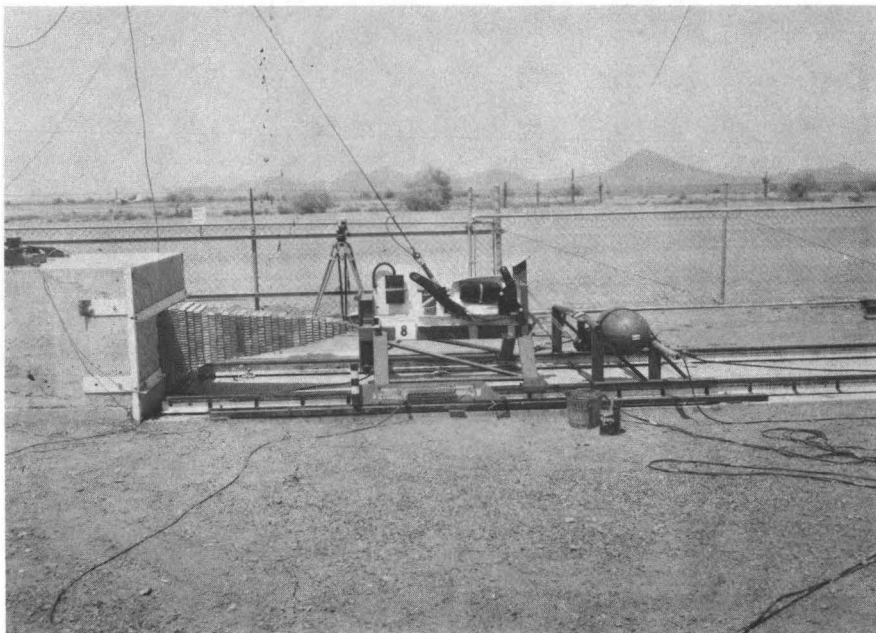


Figure F-9. Test Setup for Test 8 (three vapor storage containers and three liquid-vapor separators).

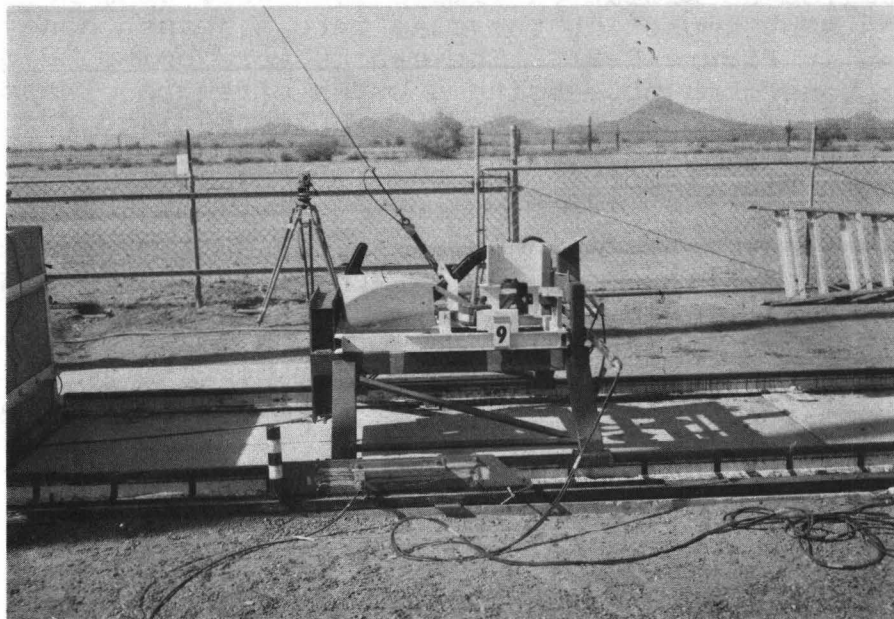


Figure F-10. Test Setup for Test 9 (three vapor storage containers and three liquid-vapor separators).

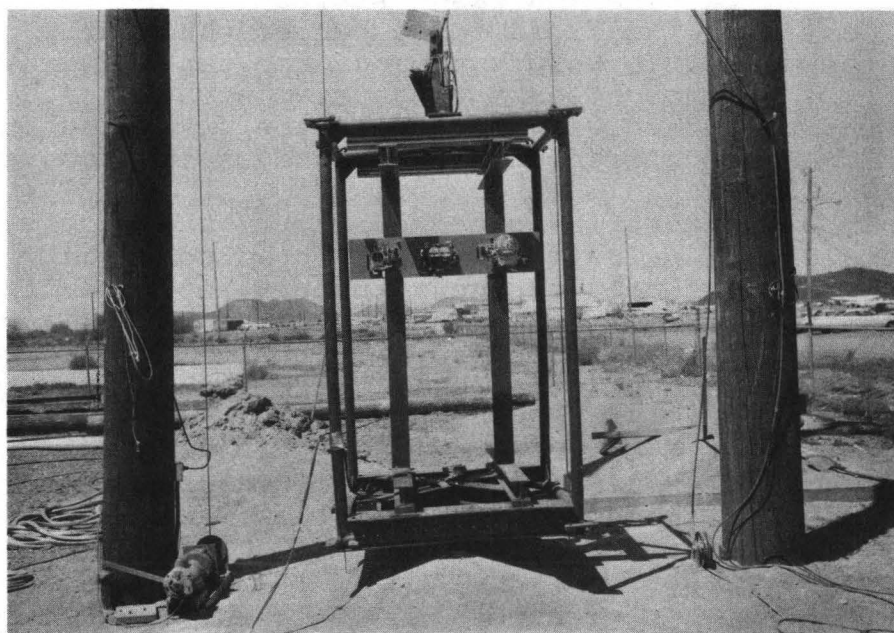


Figure F-11. Test Setup for Test 10 (three carburetors).

The desired acceleration time pulses were obtained during the sled tests by impacting the sled into a shaped honeycomb stack (shown in Figure F-9). The stacks were composed of 2-inch-thick paper honeycomb possessing a crush strength of approximately 40 psi. The high deceleration pulse desired for Test 10 was obtained by dropping the drop tower cage onto a shaped sand-pile (shown in Figure F-11).

Accelerometers were mounted on the sleds and drop tower cage to measure acceleration forces along the direction of impact. In addition, accelerometers were mounted on the fuel tanks (below the fluid level) during the subsystem tests (Tests 1 through 6). Velocities were measured and recorded immediately before impact. High-speed cameras (1,000 frames/sec) were used to record subsystem and component impact kinematics.

F.4 TEST RESULTS

The test data are shown in Table F-II. All of the deceleration pulses were representative of barrier impact pulses experienced at comparable speeds with the exception of the peak deceleration during Test No. 10, which was higher than would normally be encountered. In spite of this extremely high deceleration, the carburetors were not damaged.

The only component damaged during the entire test series was the Chevelle fuel tank, which was distorted during the rear impact test (Test 4). The fluid surge bulged the rear tank bottom and pulled the center forward bottom of the tank inward, as shown in Figure F-12. Although leakage occurred around the tank accelerometer mounting, which was located in the distorted area, no leakage would have occurred in the absence of the accelerometer.

The only attachment failure occurred in the Volkswagen subsystem test (Test 5). The fuel tank slipped completely out of the clips holding the tank to the structure, but the filler neck prevented the tank from leaving the vehicle structure (Figure F-13). The only spillage occurred when the vent line from the left forward tank vent pulled loose, allowing approximately 0.7 ounce of fluid to spill on the ground.

Although the Chevelle fuel tank shifted approximately 1 inch in the direction of impact during both Chevelle subsystem tests, the holding straps restrained the tank and no damage occurred from the tank movement.

Fuel spillage occurred around the filler cap during every test in which the filler was aligned along the direction of impact. These tests were comprised of both front and rear impacts for the Mustang and Chevelle fuel tanks (rear filler) and the side impact for the Toyota fuel tank (side filler). The spillage from the Mustang was in liquid form while the spillage from the

TABLE F-II. COMPONENT AND SUBSYSTEM ACCELERATION-TIME TEST DATA

Test No.	Test Item(s)	Direction of Impact	Accelerometer Location	Impact Velocity (ft/sec)	Maximum Deceleration (G)	Time to Maximum Deceleration (msec)	Total Deceleration Pulse Duration (msec)
1	Mustang	Front	Sled Fuel Tank	44.0 -	38.8 40.2	65.2 65.2	92.8 92.8
2	Mustang	Rear	Sled Fuel Tank	44.3 -	38.4 39.6	58.5 58.5	90.5 90.5
3	Chevelle	Front	Sled Fuel Tank	44.6 -	39.2 68.4	59.7 44.3	93.0 79.0
4	Chevelle	Rear	Sled Fuel Tank	42.7 -	44.5 - (1)	62.6 - (1)	97.2 - (1)
5	VW	Front	Sled Fuel Tank	43.7 -	40.5 87.0 (2)	62.3 62.5 (2)	95.7 115.0 (2)
6	Toyota	Rear	Sled Fuel Tank	43.3 -	40.8 51.6	70.0 69.3	100.0 90.0
7	Individual Components and Toyota Fuel Tank	Side	Sled	44.7	42.9	79.5	111.0
8	Individual Components	Front	Sled	64.9	59.4	41.5	61.0
9	Individual Components	Rear	Sled	63.5	57.2	62.0	80.5
10	Carburetors	Front	Drop Cage	43.9	295.0	6.0	13.5

(1) Fuel tank distorted in area of accelerometer.

(2) Fuel tank broke loose from attachments.

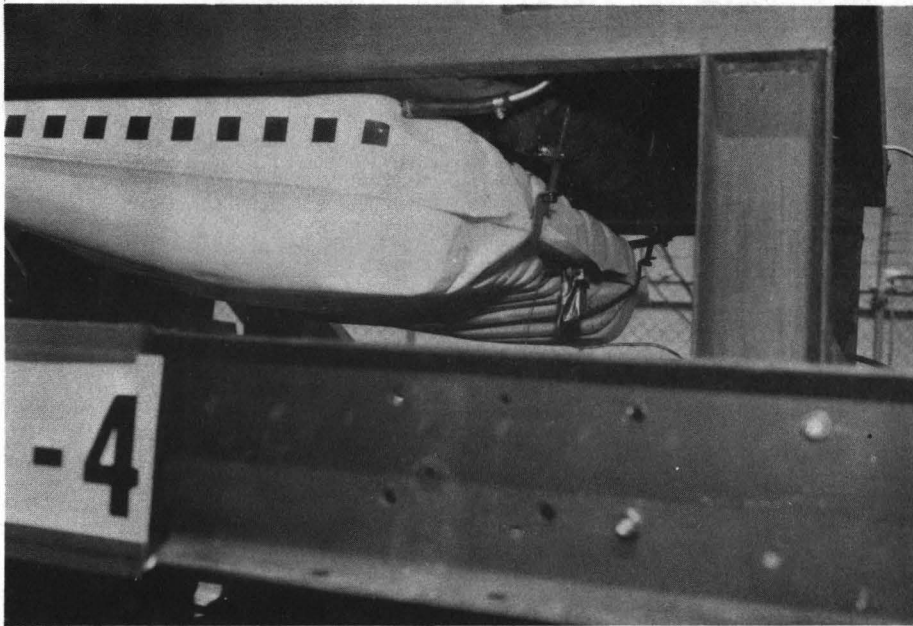


Figure F-12. Chevelle Fuel Tank Damage - Rear Impact Sled Test (Test 4).

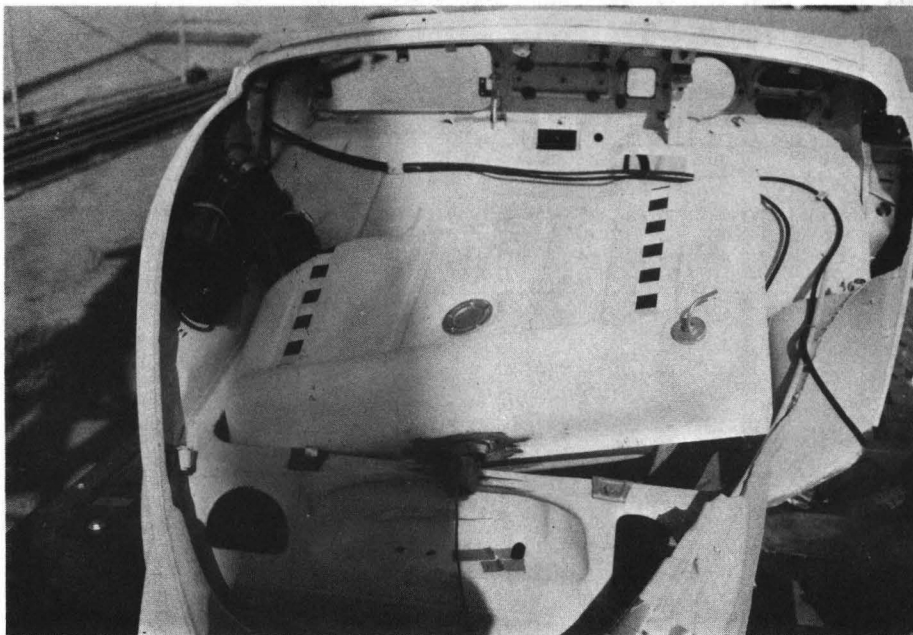


Figure F-13. Displaced Volkswagen Fuel Tank - Front Impact Sled Test (Test 5).

Toyota consisted of a fluid spray. The Chevelle spillage consisted of a short spurt of fluid which apparently was forced through the pressure relief valve in the filler cap (see Figure 5-15). The amount of fluid spilled in all cases was small.

APPENDIX G

REAR-END BARRIER TESTS

G.1 TEST OBJECTIVE

The objective of these tests was to assess the integrity of automotive fuel and fuel evaporative emission control systems in rear-end impacts.

G.2 TEST ITEMS

The five vehicles tested were:

1970 Chevelle Malibu	1971 Ford Pinto
1970 Toyota Corolla	1971 Dodge Polara Station Wagon
1970 AMC Ambassador	

These vehicles were previously front-end barrier crashed under other NHTSA contracts. Deformed sheet metal structure was removed and minor repairs were made to the front ends of the vehicles to enable them to track down the roadway into the impact barrier.

G.3 TEST PROCEDURES

The tests were conducted on the full-scale crash test facility shown in Figure G-1. The vehicles were towed backwards into a steel load acquisition module attached to a reinforced concrete barrier conforming to SAE J850. The vehicle fuel tanks were filled to 91 percent capacity with Stoddard Type II solvent. The vehicles were then ballasted to their approximate Gross Vehicle Weight Rating with sandbags or steel plates.

Accelerometers were mounted on each vehicle in the positions shown in Table G-I. Vehicle velocity was measured just prior to impact by two speed traps located a few feet from the barrier. Three high-speed cameras (1000 frames/sec) were used to record the crash dynamics of the Chevelle, Ambassador, Pinto, and Dodge station wagon. These cameras consisted of a ground-based broadside camera, an overhead camera, and a pit camera. Only the broadside and overhead cameras were used during the Toyota test as the fuel and vapor tanks were not visible from beneath the vehicle.

The test weights and impact velocities of the vehicles are shown in Table G-II.

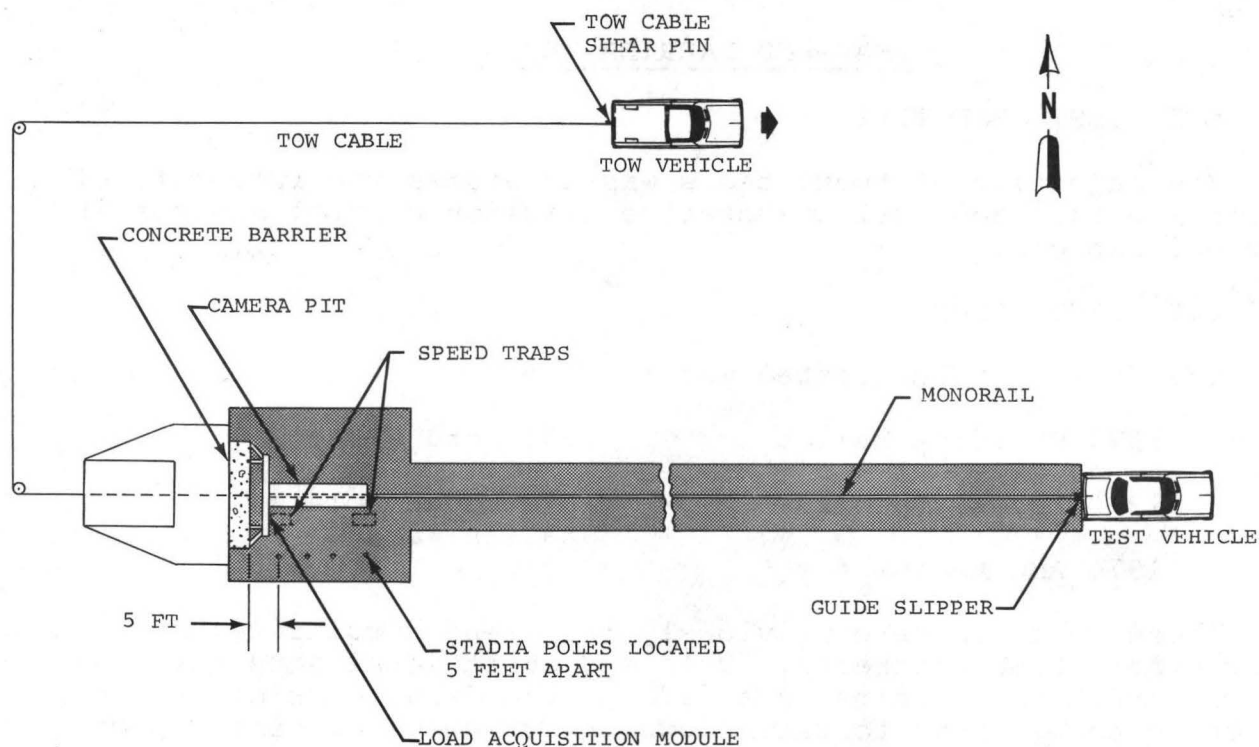


Figure G-1. Full-Scale Crash Test Facility.

TABLE G-I. ACCELEROMETER LOCATIONS	
Location	Number and Direction
Occupant Compartment - Center - On Tunnel	Triaxial
Engine	Triaxial
Frame - Underneath "B" Pillar - Left Side	Biaxial (longitudinal and vertical)
Frame - Underneath "B" Pillar - Right Side	Uniaxial (longitudinal)
Vehicle Structure in Area of Fuel Tank	Biaxial (longitudinal and vertical)

TABLE G-II. VEHICLE WEIGHTS AND IMPACT VELOCITIES

Test No.	Vehicle	Vehicle Test Weight (lb)	Impact Velocity (mph)
223-1	1970 Toyota Corolla	2,345	30.2
223-2	1971 Dodge Station Wagon	5,795	27.6
223-3	1970 Chevelle Malibu	4,176	21.8
223-4	1970 AMC Ambassador	4,530	20.2
223-5	1971 Ford Pinto	2,685	20.1

G.4 INDIVIDUAL TEST RESULTS

G.4.1 Toyota Corolla. Pre- and post-test views of the vehicle are shown in Figure G-2. Post-test measurements showed that the vehicle rebounded 39-3/4 inches from the barrier. Maximum permanent crush of the vehicle was 24-1/4 inches; most of this occurred between the rear bumper and the rear axle (18-1/2 inches).

High-speed film analysis showed that the vehicle structure behind the rear wheels crushed horizontally between the barrier and the still forward-moving wheels. As the wheels continued moving toward the barrier, the structure above the rear wheels buckled up and crushing also occurred in this area. The rear wheels left the ground momentarily at maximum vehicle crush (dynamic crush equaled 32-1/4 inches). The front wheels also left the ground at this time and did not touch down again until the vehicle had rebounded approximately 9 inches from the barrier. Some elastic deformation was noted in the structure above and forward of the rear wheels, but nearly all of the deformation aft of the rear wheels was permanent.

Examination of the vehicle disclosed that approximately 0.3 ounce (by weight) of fluid surged through the broken filler neck-fuel tank vapor line connection on top of the fuel tank (see Figure 5-48). This soldered connection had been broken by the impact of the vapor storage tank (located above the fuel tank). The fuel tank itself was not impacted by either the barrier or the crushed vehicle structure due to its forward location above the rear axle. There was no post-impact fluid leakage.

The deformation of the vehicle structure did pull the fuel feed hose from the tank off of the metal feed line leading to the engine compartment as shown in Figure 5-48. No fluid leakage occurred from the separated line on impact or thereafter.

Unfortunately, a malfunction of the magnetic tape recorder precluded the acquisition of data from the accelerometers mounted on the vehicle and from the barrier load cells.

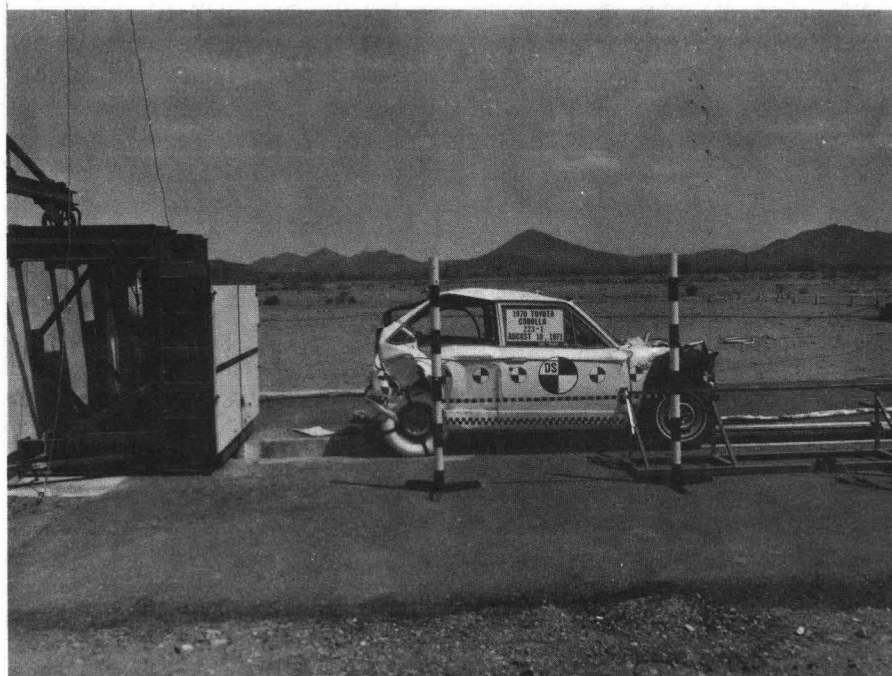


Figure G-2. Pre- and Post-test Views of Toyota Corolla.

G.4.2 Dodge Station Wagon. Pre- and post-test views of the vehicle are shown in Figure G-3. The impact caused the rear frame to buckle up extensively above and immediately forward of the rear axle, thus allowing the whole rear body structure to move forward. The passenger compartment was buckled badly in the rear seat back area.

Post-test measurements showed the vehicle rebounded 5 inches from the barrier. A permanent maximum crush of 20-1/2 inches occurred on both sides of the vehicle. However, the two sides of the vehicle exhibited different crushing characteristics. The left side of the vehicle, which contains the fuel tank in the left rear quarter panel, crushed 10-1/8 inches between the rear bumper and rear axle, while the right side crushed 15-3/8 inches in the same area. A larger crush on the left side between the "B" and "C" pillars accounts for the total crush of the two sides being identical.

The different crush characteristics of the two sides of the vehicle were probably due to the location of the fuel tank. The nearly full tank was compressed between the rear structure of the vehicle and the left rear tire during impact, essentially stiffening the left rear quarter structure and transmitting more of the force into the structure ahead of the rear axle.

High-speed film analysis revealed that approximately 7 inches of crush occurred in the extreme rear structure of the vehicle before the frame started to buckle. Once the frame began buckling, the majority of the remaining crush occurred due to the buckling of the structure over the rear wheels as the front of the vehicle continued to travel toward the barrier. There was some elastic crushing which occurred mainly in the buckled structure over the rear wheels. Maximum dynamic crush was 24-3/4 inches.

A fluid surge sufficient to wet approximately 1 square foot of ground near the left rear wheel occurred upon impact. Post-impact spillage of 1/4 oz/min from the left rear fender area stopped completely within 3 minutes. Examination of the vehicle disclosed that the projecting flange on the filler cap had been struck by the rear filler well structure, loosening the cap and allowing fluid to surge from the filler at impact. No other spillage occurred.

The accelerometer and barrier load cell data are shown in Figures G-4 through G-8. Total velocity change and impulse curves derived from integrating the accelerometer and barrier load cell traces are shown in Figures G-9 through G-11.

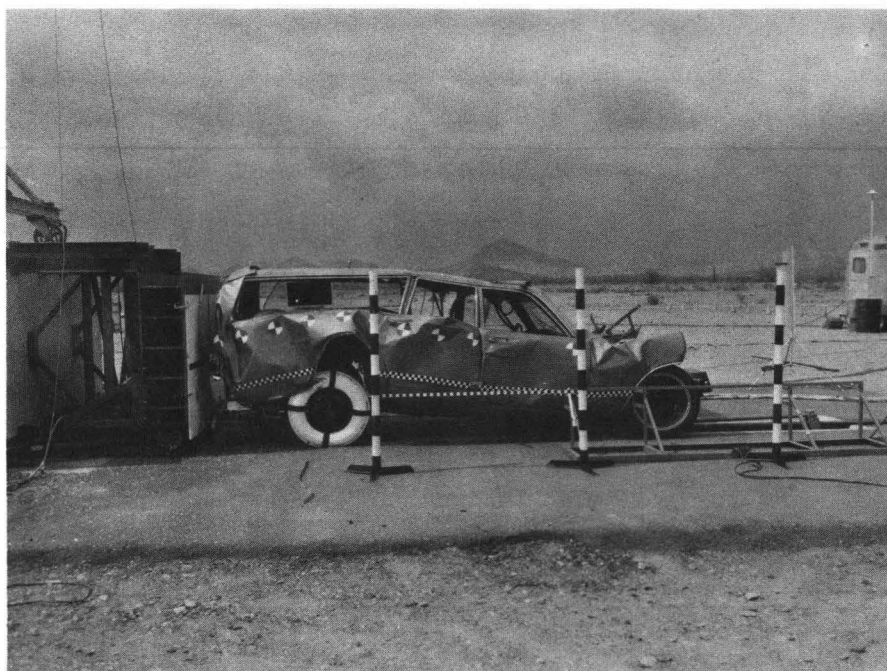
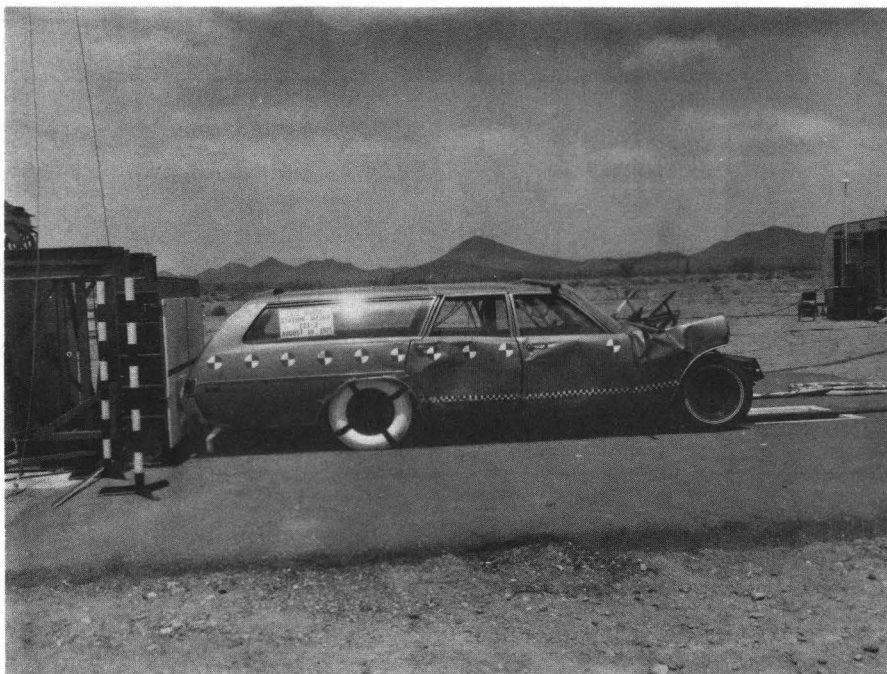


Figure G-3. Pre- and Post-test Views of Dodge Station Wagon.

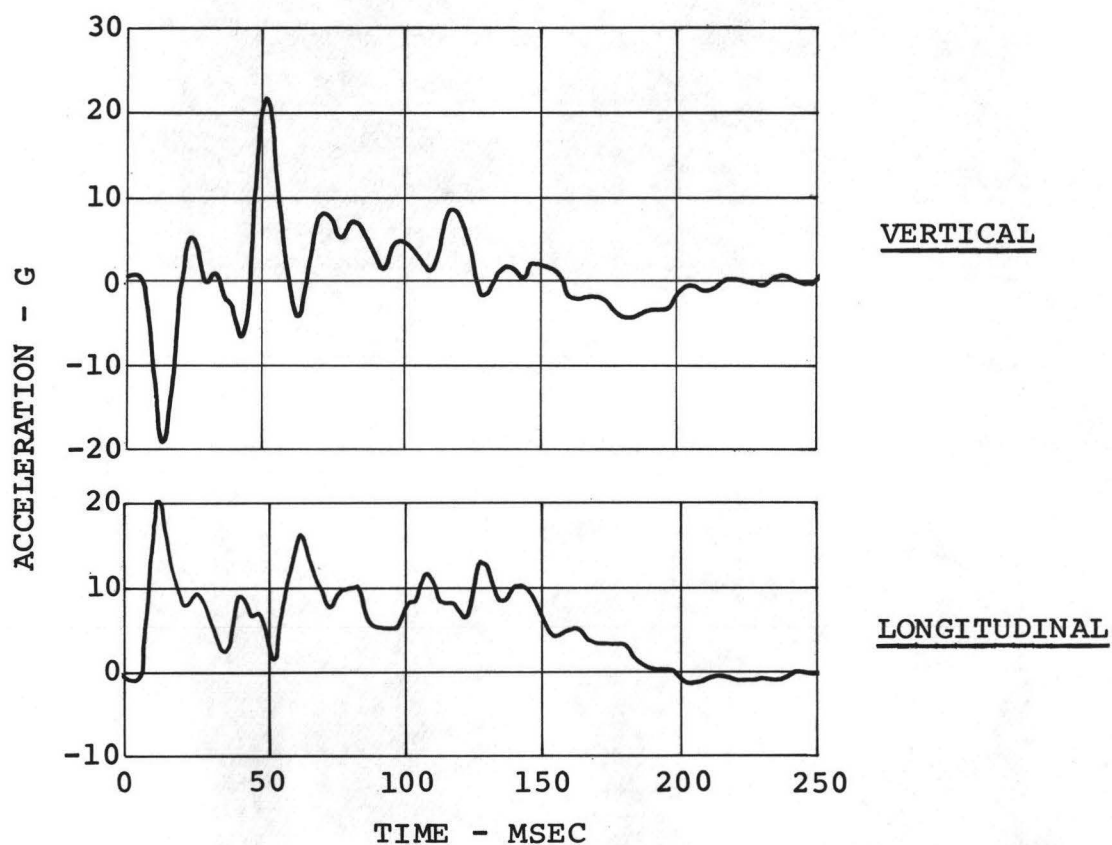


Figure G-4. Acceleration-Time Histories, Occupant Compartment - Dodge Station Wagon.

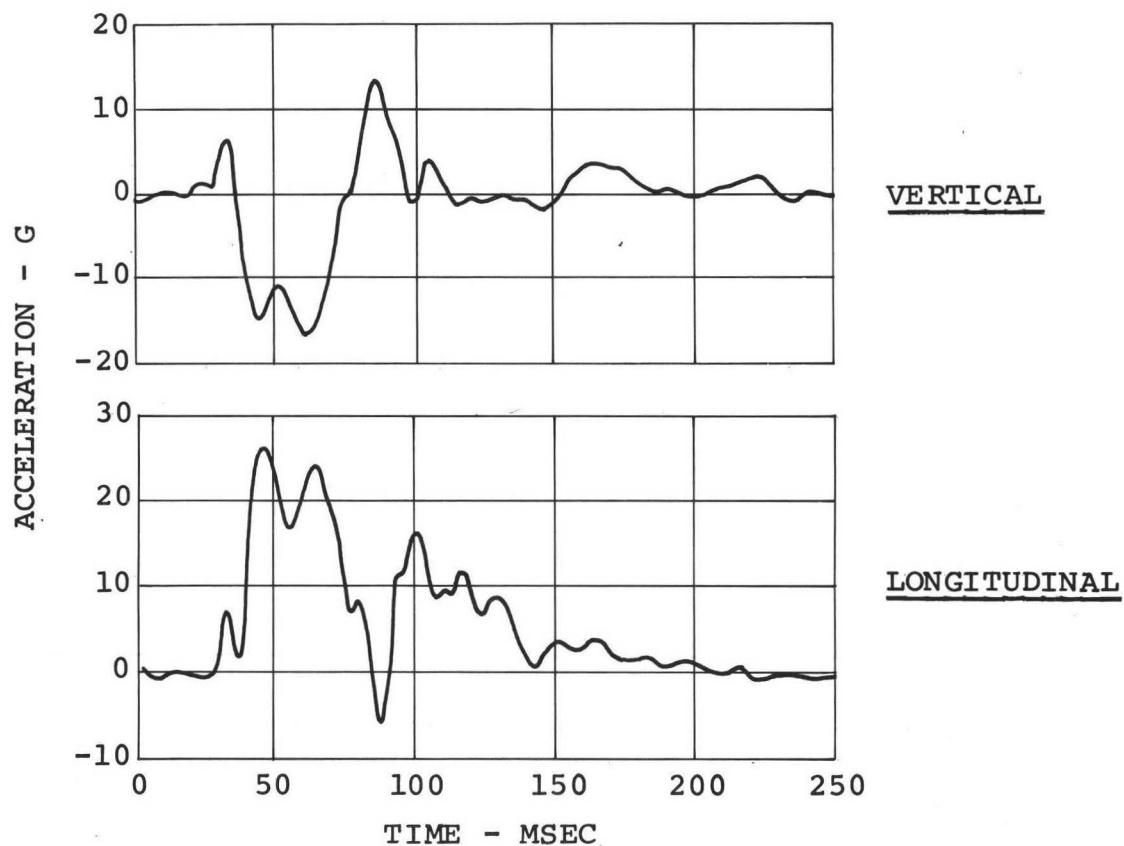


Figure G-5. Acceleration-Time Histories, Engine - ,
Dodge Station Wagon.

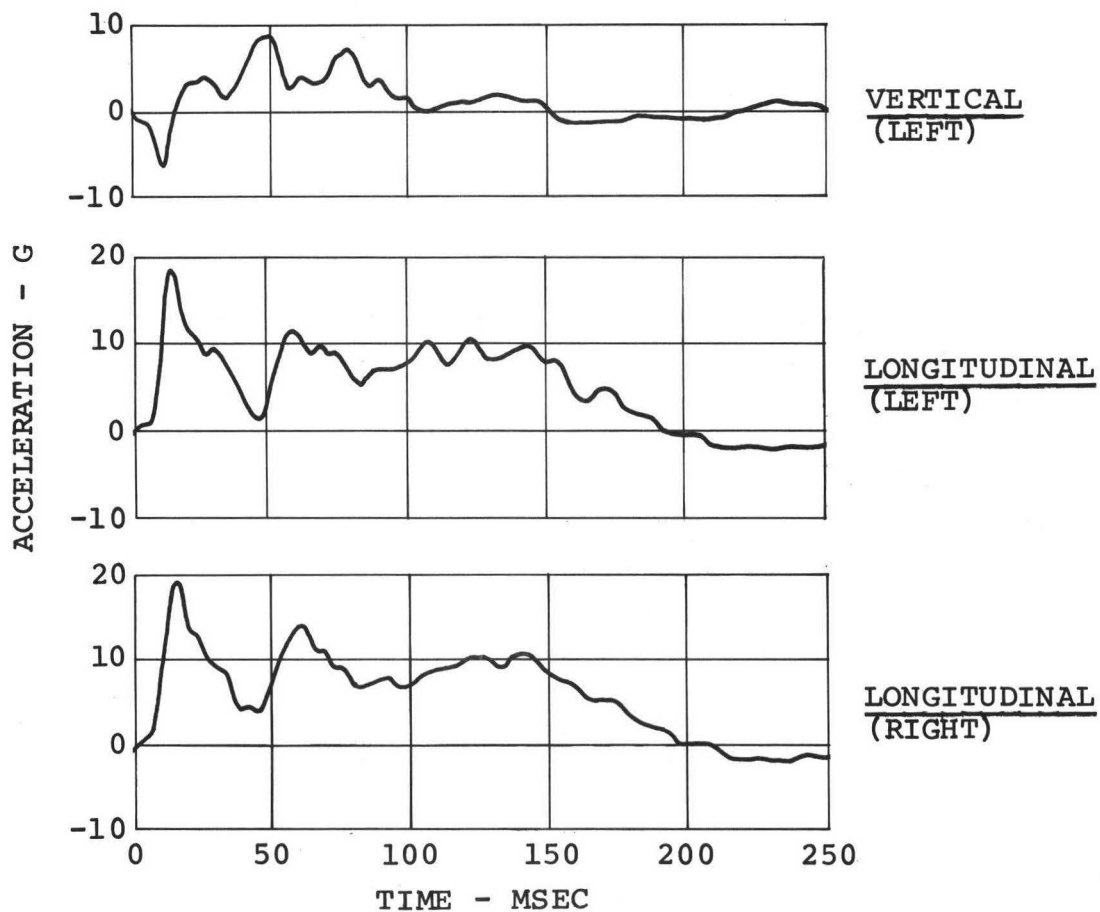


Figure G-6. Acceleration-Time Histories, Frame - Dodge Station Wagon.

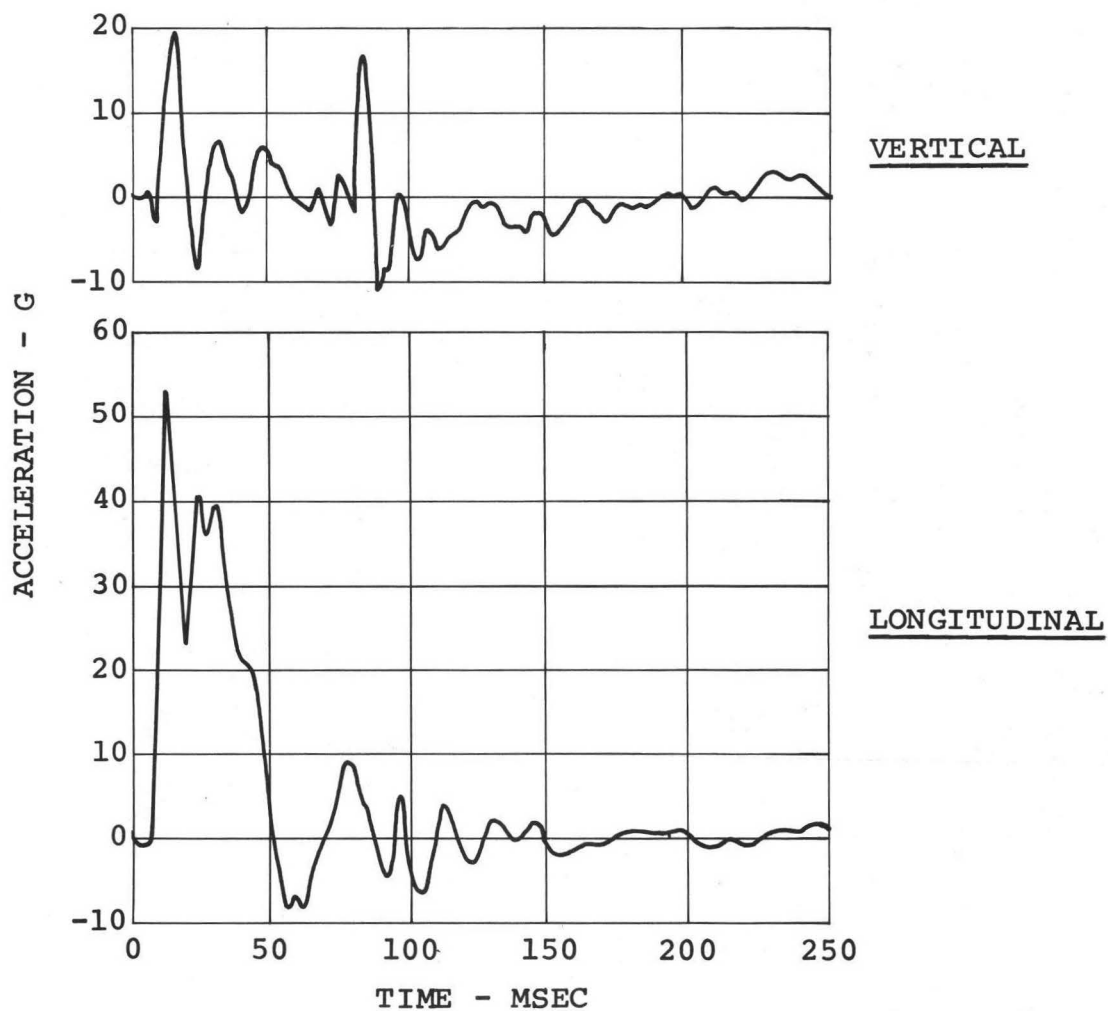


Figure G-7. Acceleration-Time Histories, Fuel Tank Area - Dodge Station Wagon.

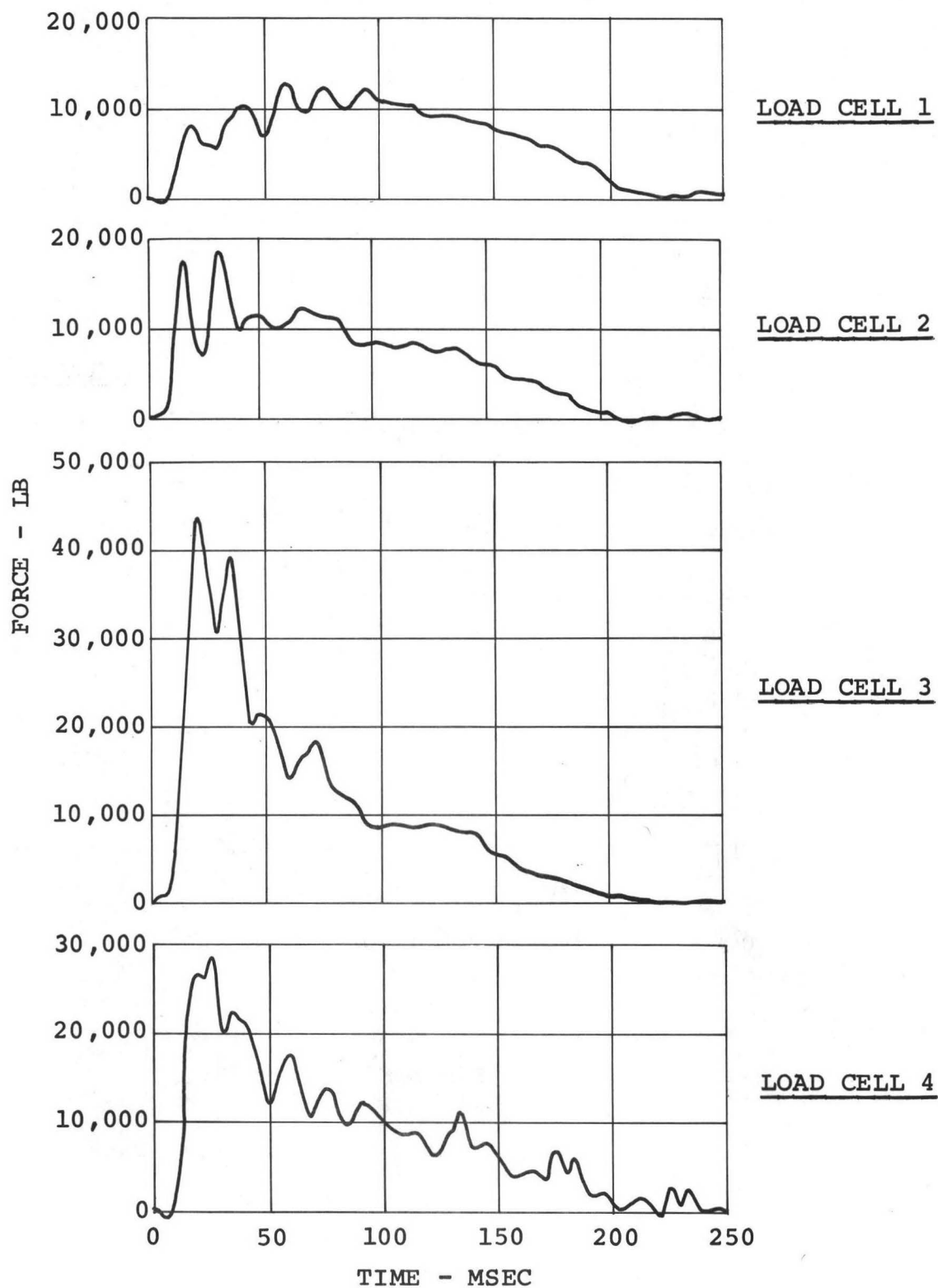


Figure G-8. Force-Time Histories, Barrier Load Cells - Dodge Station Wagon.

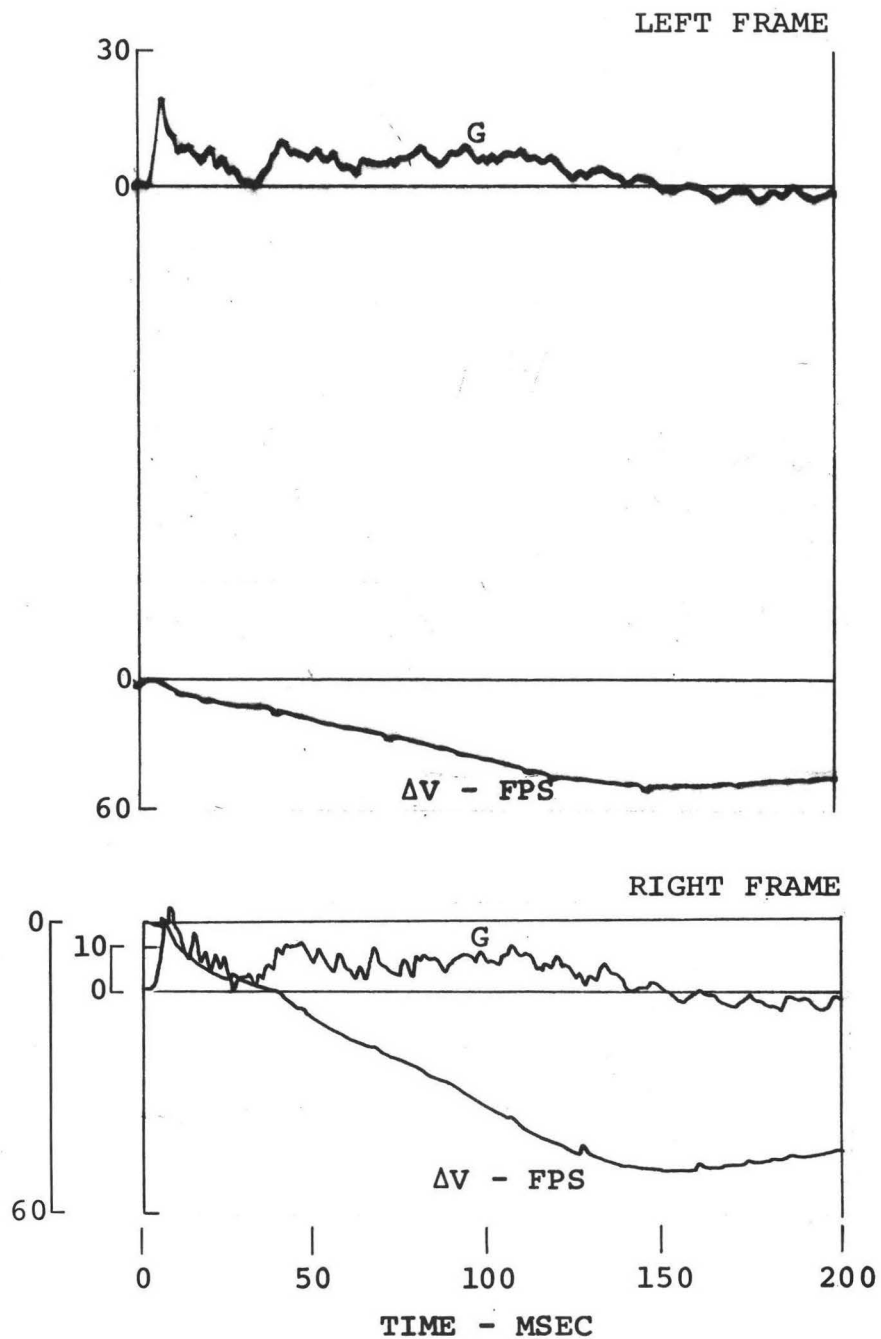


Figure G-9. Longitudinal Acceleration-Time Histories and Velocity Changes - Dodge Station Wagon.

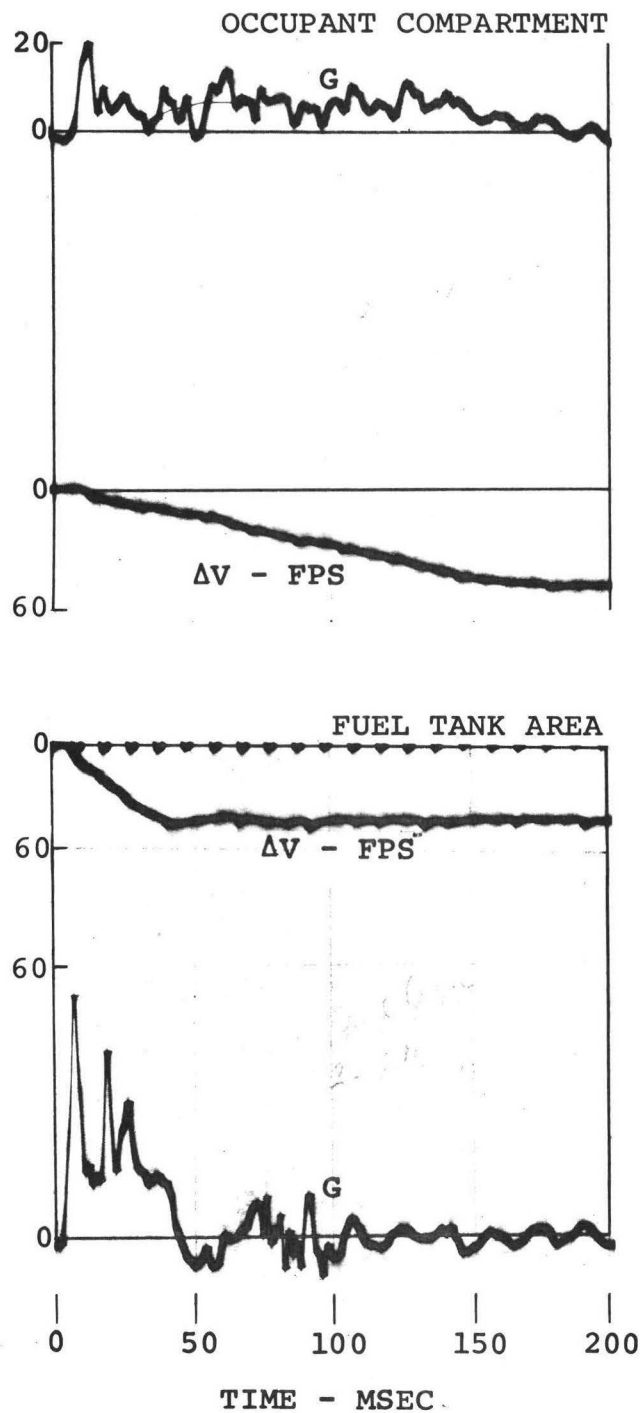


Figure G-10. Longitudinal Acceleration-Time Histories and Velocity Changes - Dodge Station Wagon.

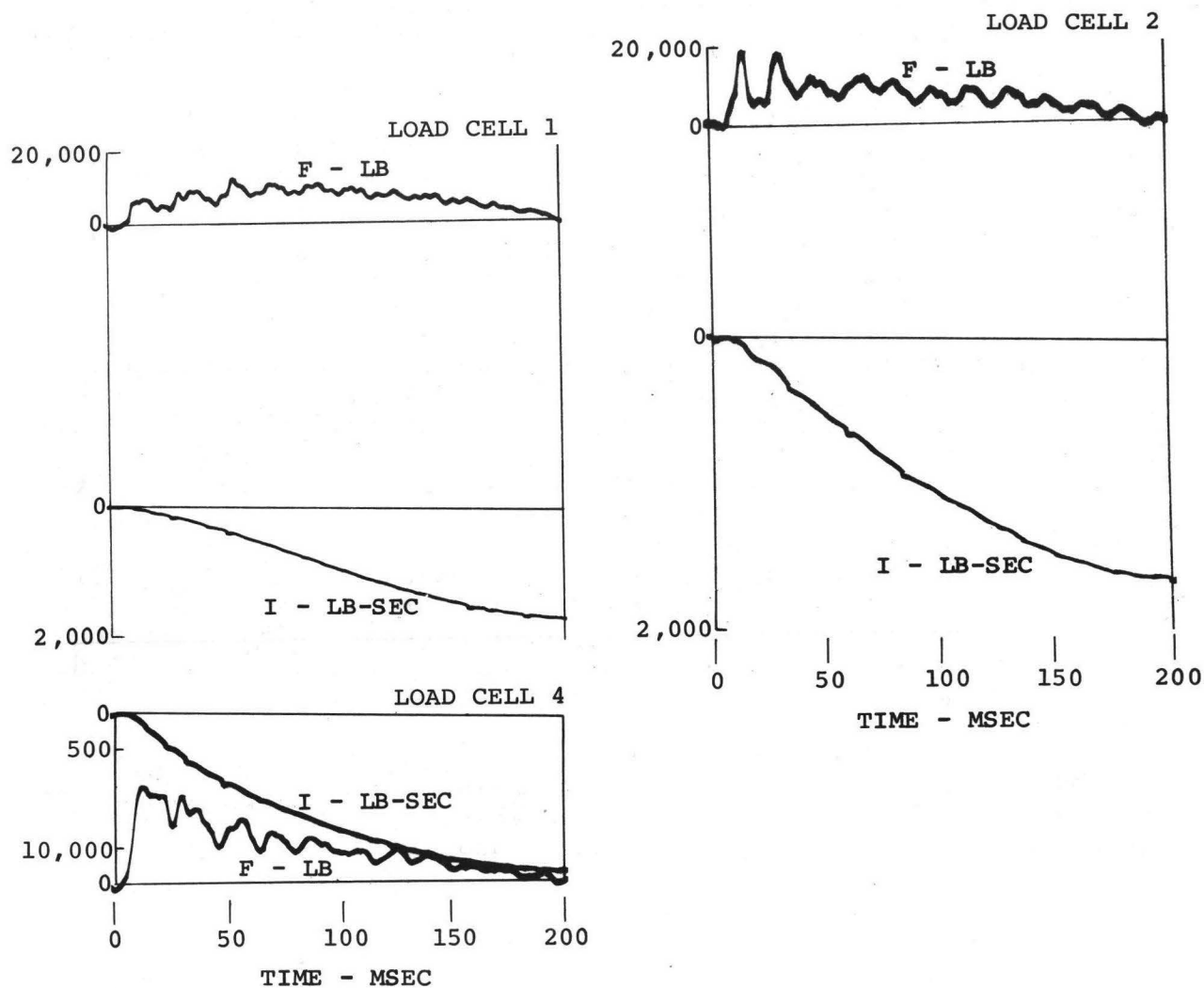


Figure G-11. Force-Time Histories and Impulses, Barrier Load Cells - Dodge Station Wagon (No impulse data trace available for Load Cell 3).

G.4.3 Chevelle Malibu. Pre- and post-test views of the vehicle are shown in Figure G-12. Examination revealed that the frame buckled downward approximately 1 foot forward of the rear frame cross member and buckled upward above the rear axle, allowing the whole rear structure behind the axle to move forward.

Post-test measurements showed a maximum permanent crush of 23-1/2 inches. Of this, 22-3/4 inches occurred between the rear bumper and rear axle. The vehicle rebounded 5-1/2 inches from the barrier.

The high-speed film revealed that approximately the first three-fourths of the maximum dynamic crush (27-1/2 inches) occurred in the structure behind the rear axle. At this point, the rear wheels stopped and the body structure overrode the wheels until maximum crush occurred. The majority of the latter crushing was elastic as the structure rebounded back over the rear wheels before the vehicle came to rest.

Post-test fluid spillage averaged 2.2 oz/min between the second and fifth minute after impact. This spillage occurred at the filler pipe-fuel tank connection. During impact, the filler pipe was trapped between the rear frame cross member (which moved up as the frame buckled) and the trunk floor pan, crushing the pipe and partially pulling it from the soldered connection in the tank. At the same time, the film analysis revealed that the fuel tank, which was first crushed in the front center by the differential housing, rode partially up and over the differential, pulling the rear of the tank downward and further pulling on the filler pipe-tank connection. Although the fuel tank was badly deformed, the only spillage occurred at the filler pipe-tank connection.

The accelerometer and barrier load cell data are shown in Figures G-13 through G-17. Total velocity change and impulse curves are shown in Figures G-18 through G-21.

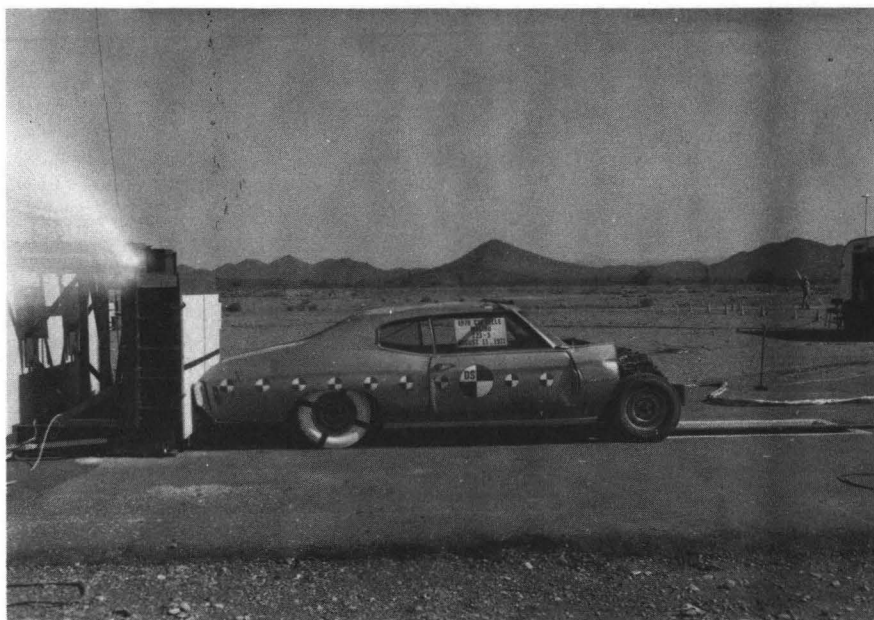


Figure G-12. Pre- and Post-test Views of Chevelle Malibu.

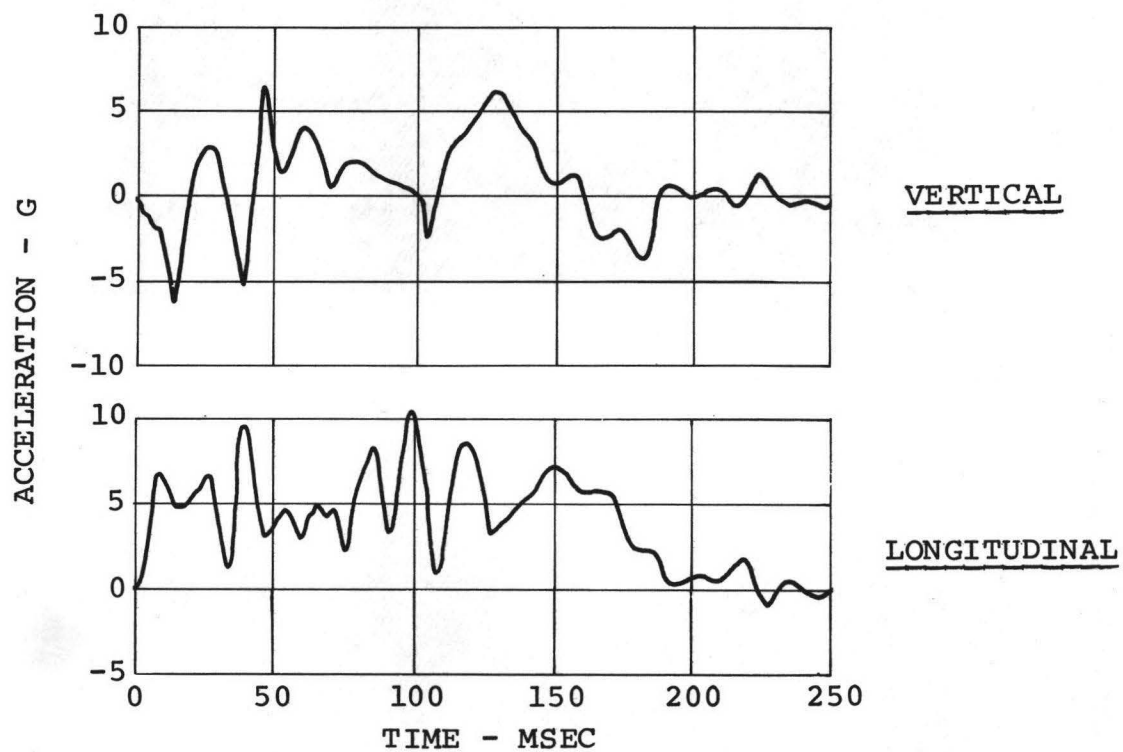


Figure G-13. Acceleration-Time History, Occupant Compartment - Chevelle.

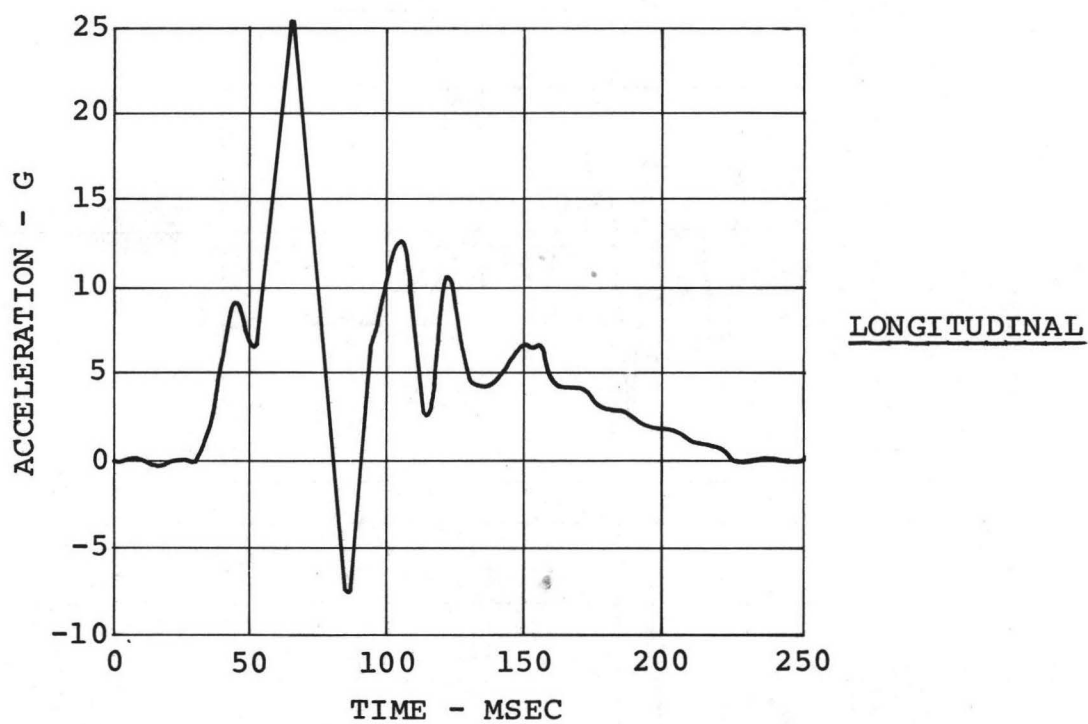


Figure G-14. Acceleration-Time History, Engine - Chevelle.

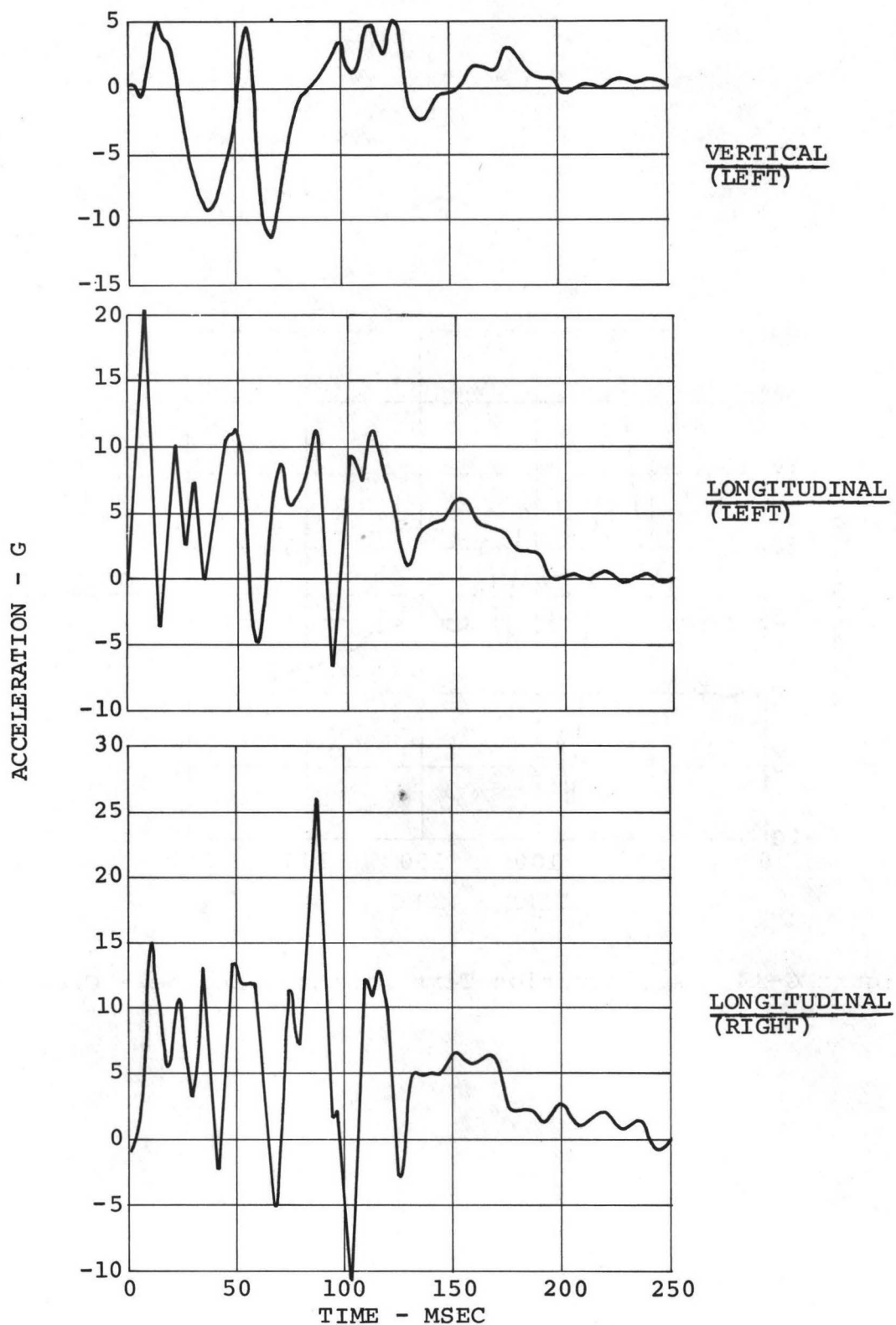


Figure G-15. Acceleration-Time Histories, Frame - Chevelle.

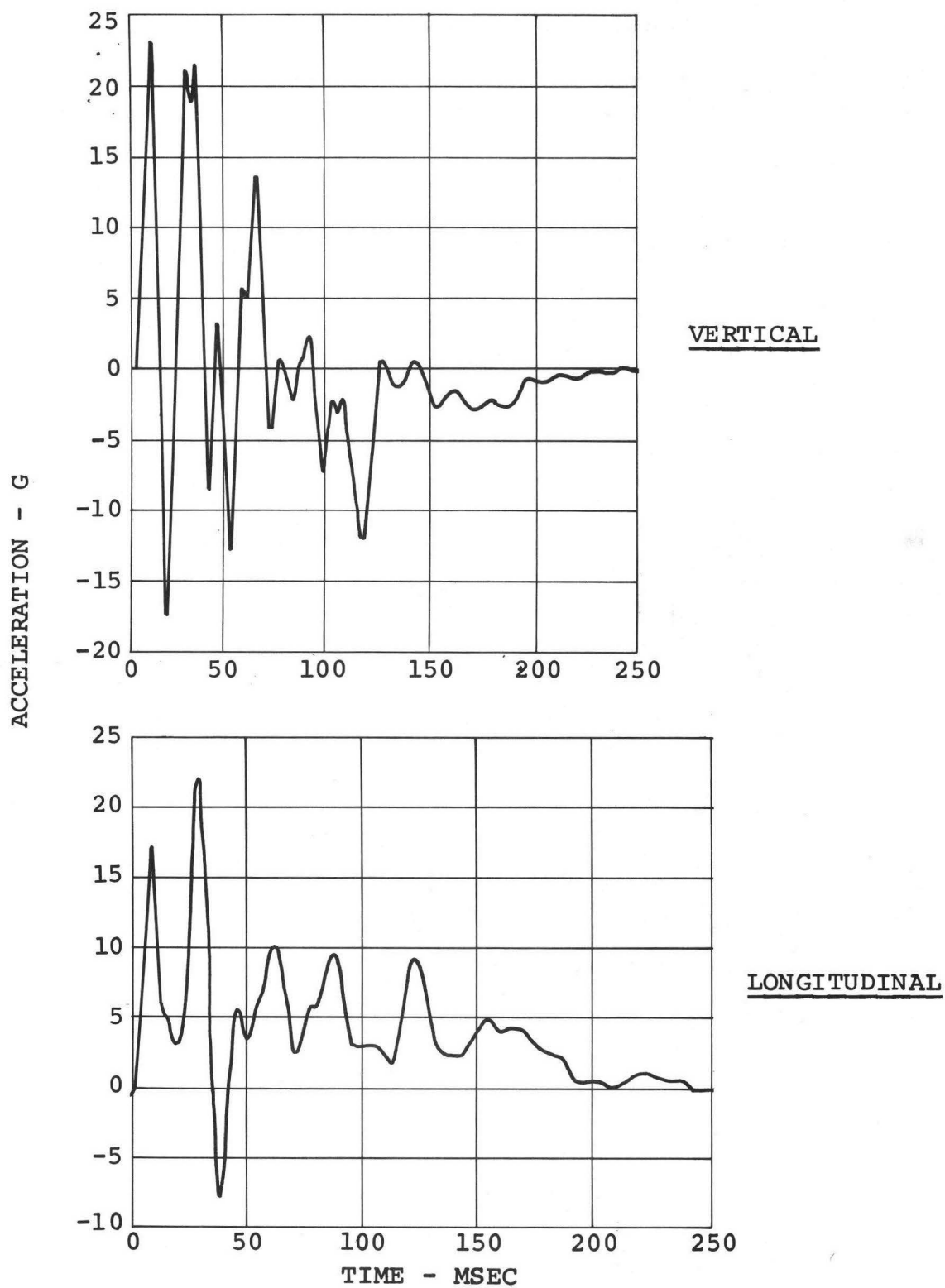


Figure G-16. Acceleration-Time Histories, Fuel Tank Area - Chevelle.

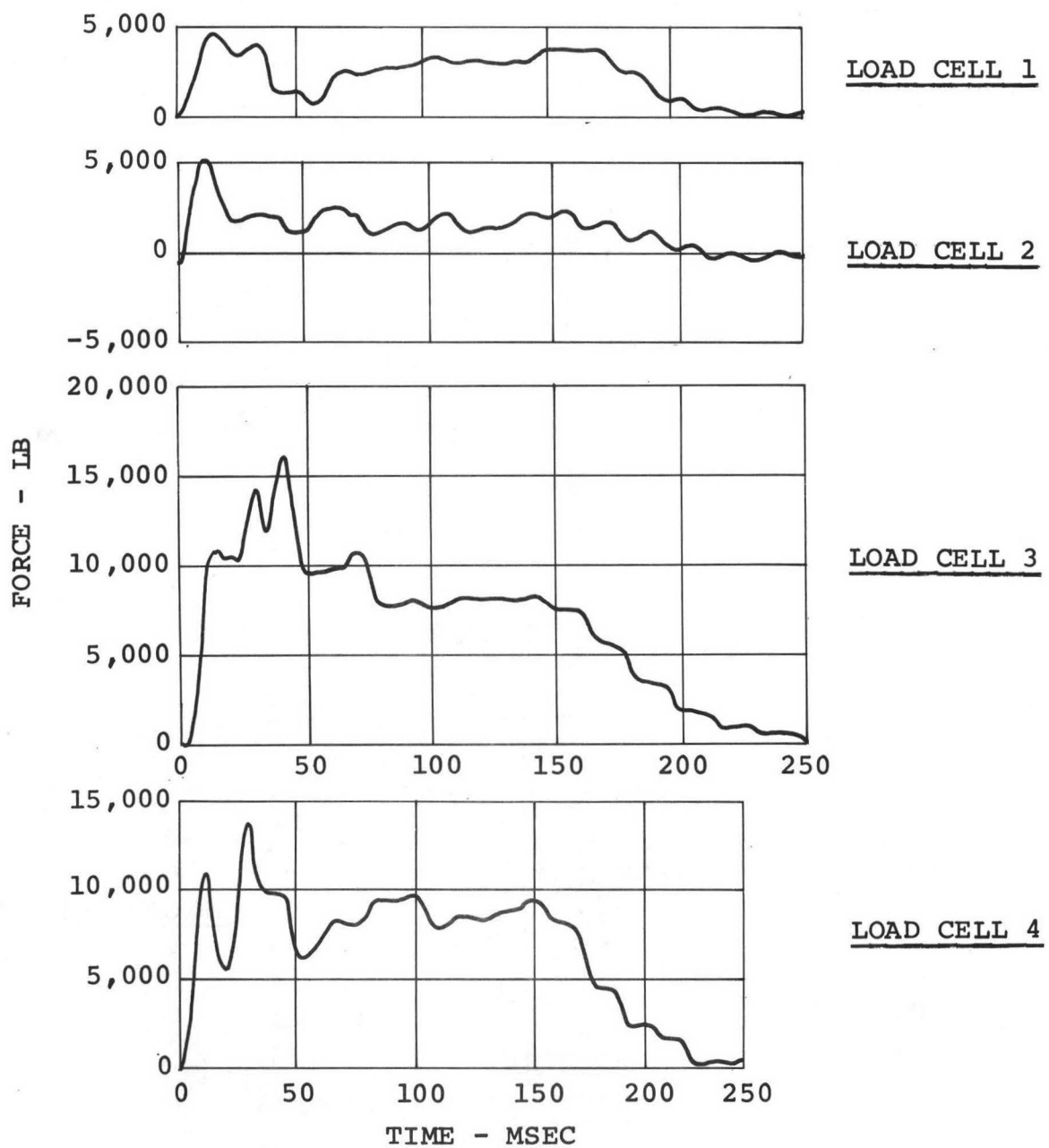


Figure G-17. Force-Time Histories, Barrier Load Cells - Chevelle.

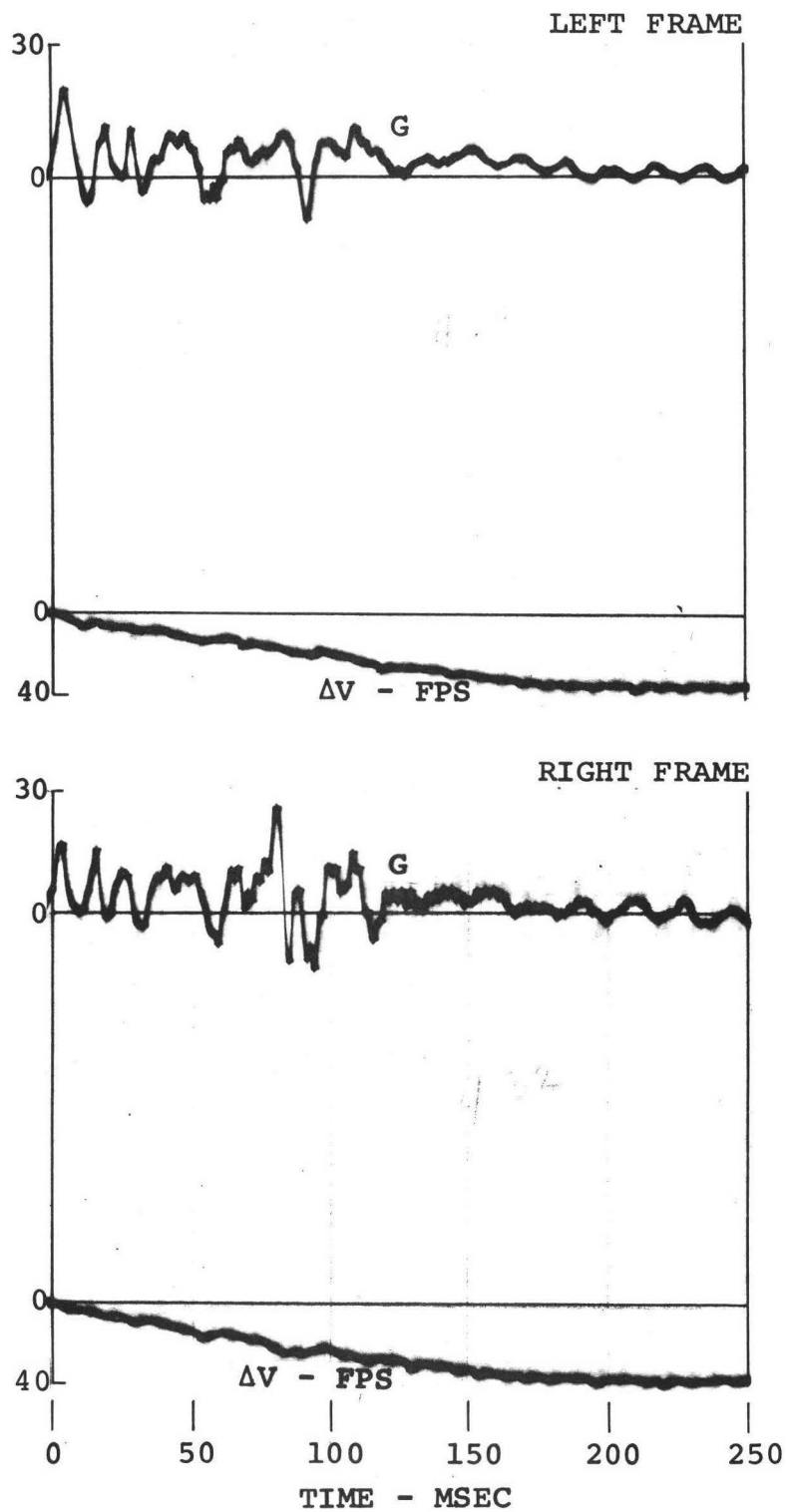


Figure G-18. Longitudinal Acceleration-Time Histories and Velocity Changes - Chevelle.

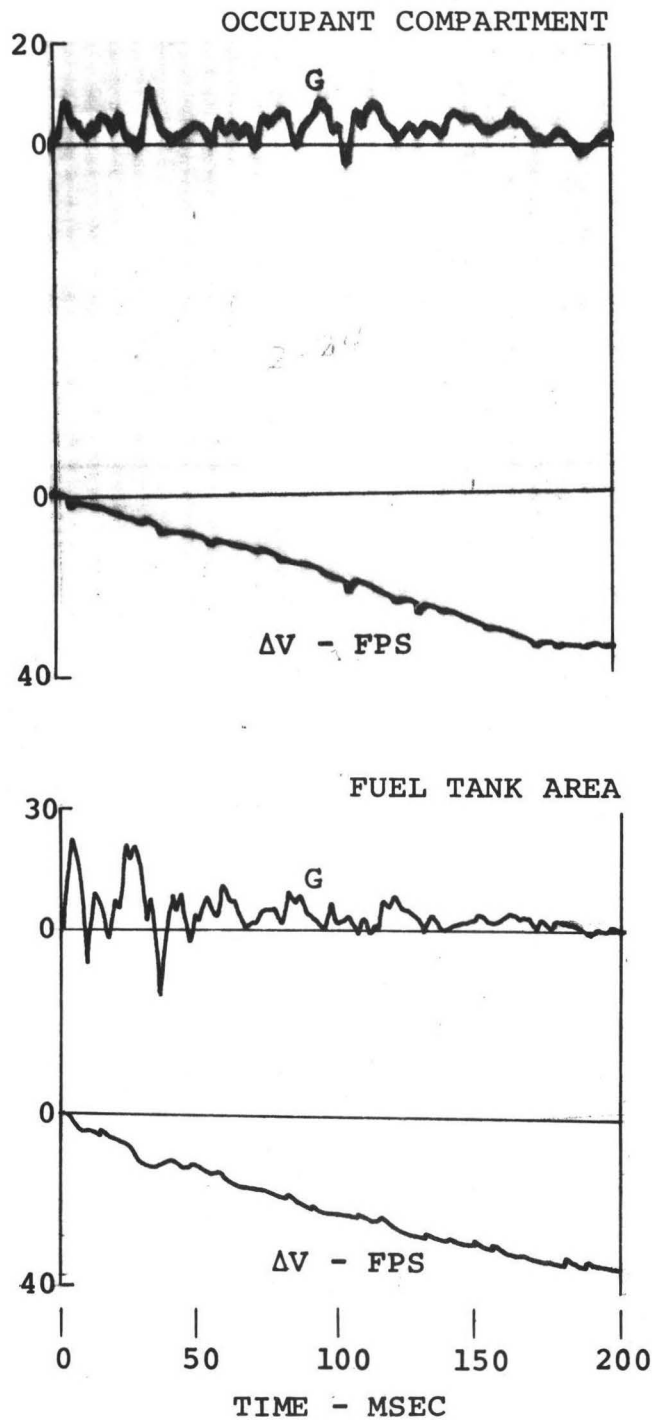


Figure G-19. Longitudinal Acceleration-Time Histories and Velocity Changes - Chevelle.

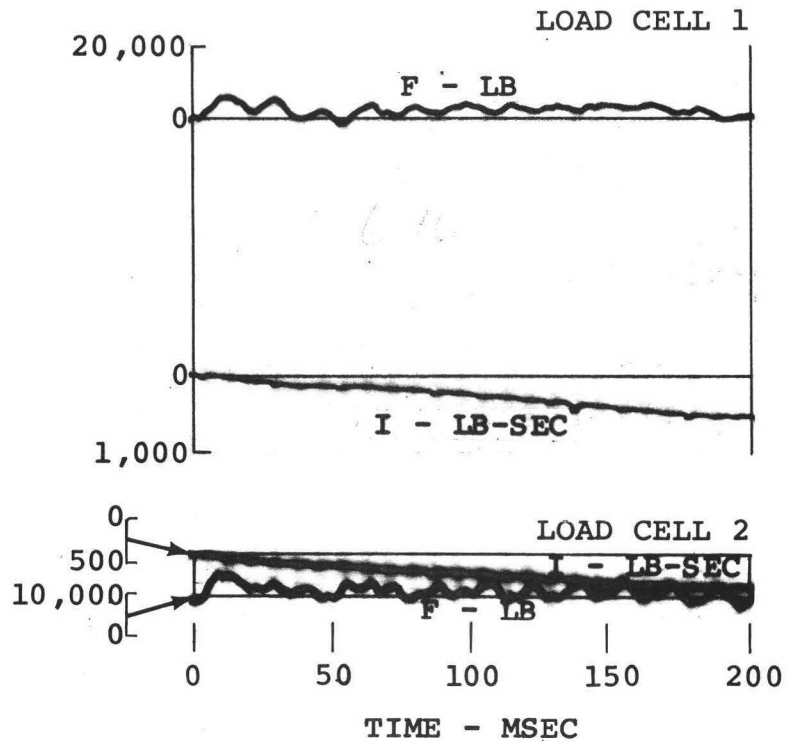


Figure G-20. Force-Time Histories and Impulses, Barrier Load Cells - Chevelle.

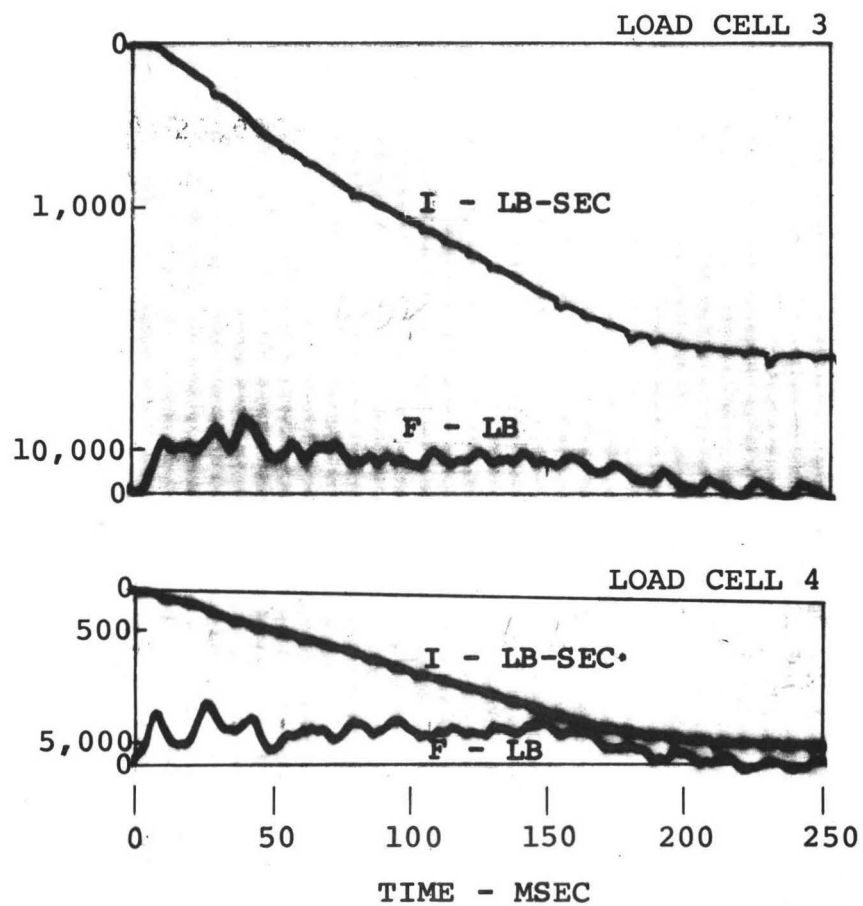


Figure G-21. Force-Time Histories and Impulses, Barrier Load Cells - Chevelle.

G.4.4 AMC Ambassador. Pre- and post-test views of the vehicle are shown in Figure G-22. Post-test measurements showed the maximum permanent crush was 20-7/8 inches. Of this, 20-3/8 inches occurred between the rear bumper and rear axle. The vehicle rebounded 3 inches from the barrier.

High-speed film analysis revealed that the rear vehicle structure began to crush horizontally at impact. However, the rear wheels left the ground well before maximum crush occurred and overrode the rear structure, further crushing it and forcing the extreme rear structure downward. The rear wheels were 7-1/4 inches off the ground at maximum crush. The maximum dynamic crush measured 25-1/2 inches.

There was no impact or post-impact leakage although the differential housing struck the front center of the fuel tank and crushed it inward 4 inches. The high-speed film showed that the differential housing also struck the fuel feed line at the front of the tank, bending it rearward but not breaking it.

Examination of the vehicle disclosed that the rubber section of the vapor line leaving the right front corner of the tank had been torn where it connects to the metal portion of the line leading to the liquid check valve (see Figure 5-61). This tear occurred approximately 6 inches from the tank outlet and was apparently caused by the hose being caught between the crushed vehicle structure and the right rear shock absorber or spring.

The accelerometer and barrier load cell data are shown in Figures G-23 through G-27. Total velocity change and impulse curves are shown in Figures G-28 and G-29.

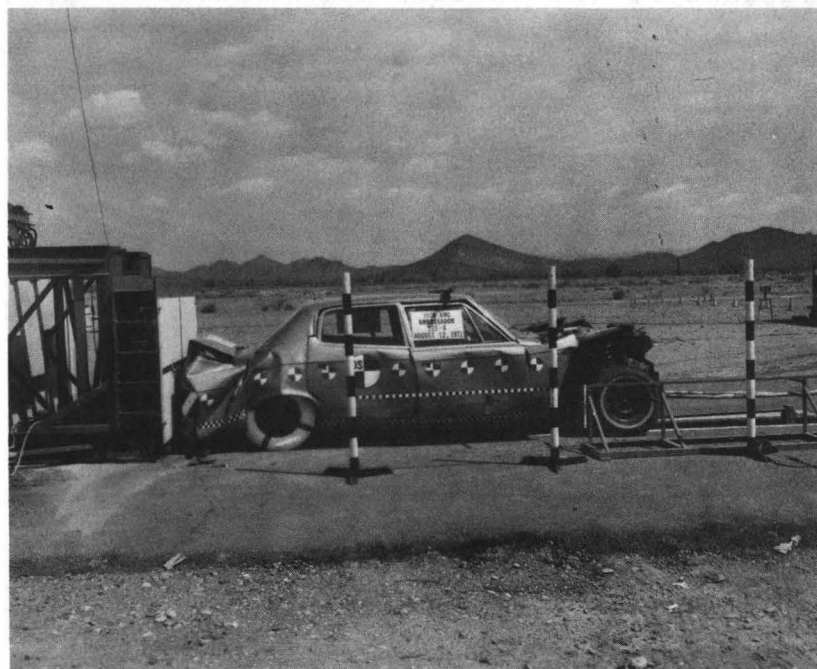


Figure G-22. Pre- and Post-test Views of AMC Ambassador.

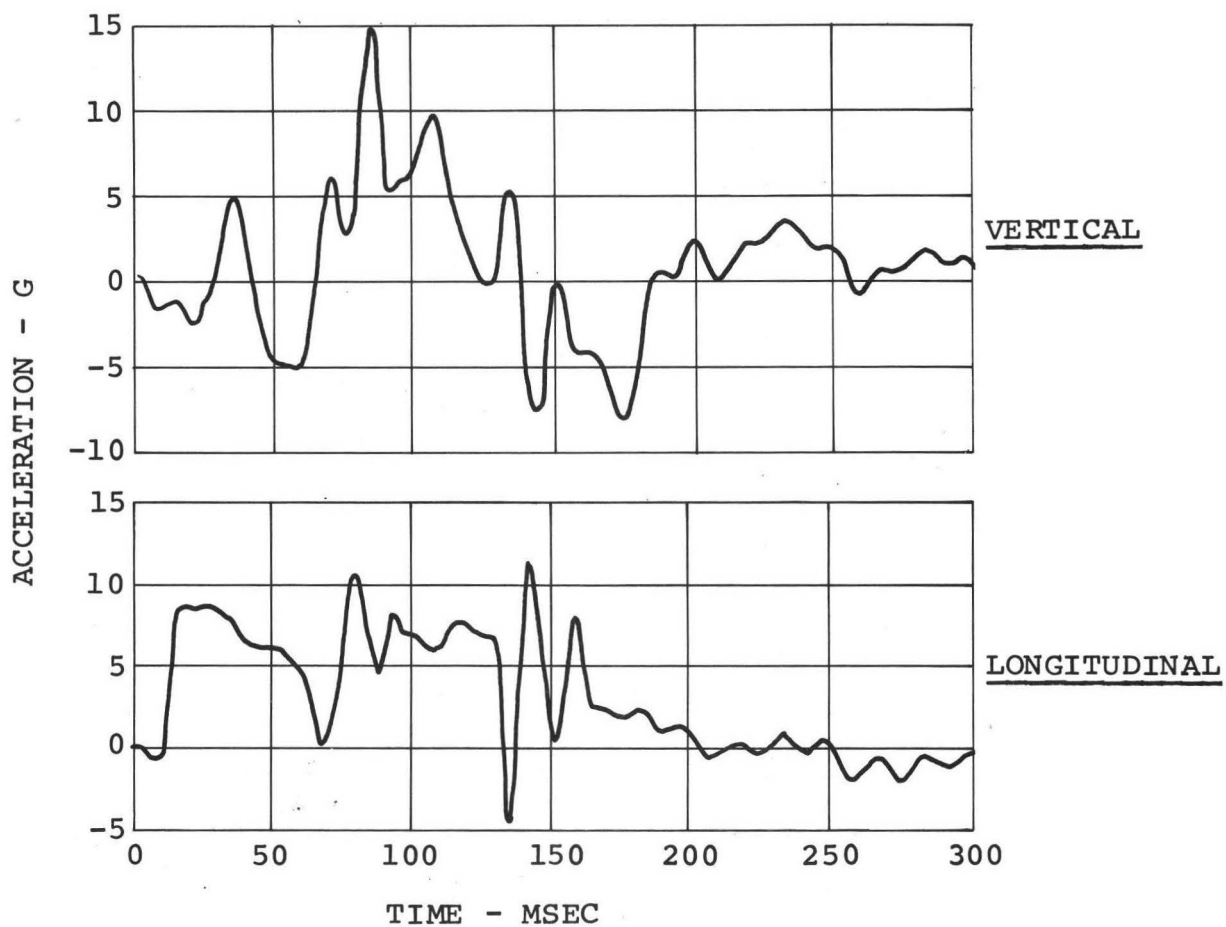


Figure G-23. Acceleration-Time Histories, Occupant Compartment - AMC Ambassador.

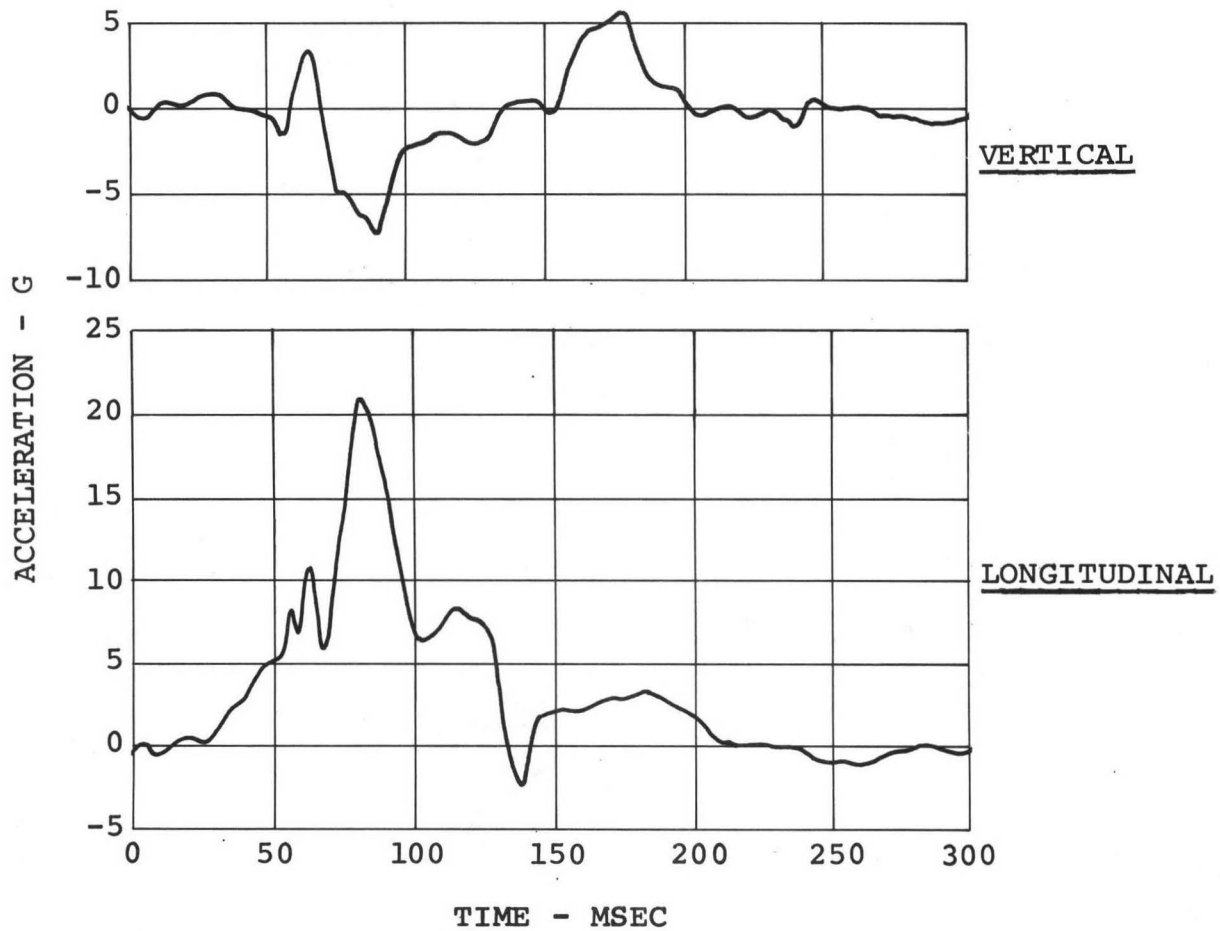


Figure G-24. Acceleration-Time Histories, Engine - AMC Ambassador.

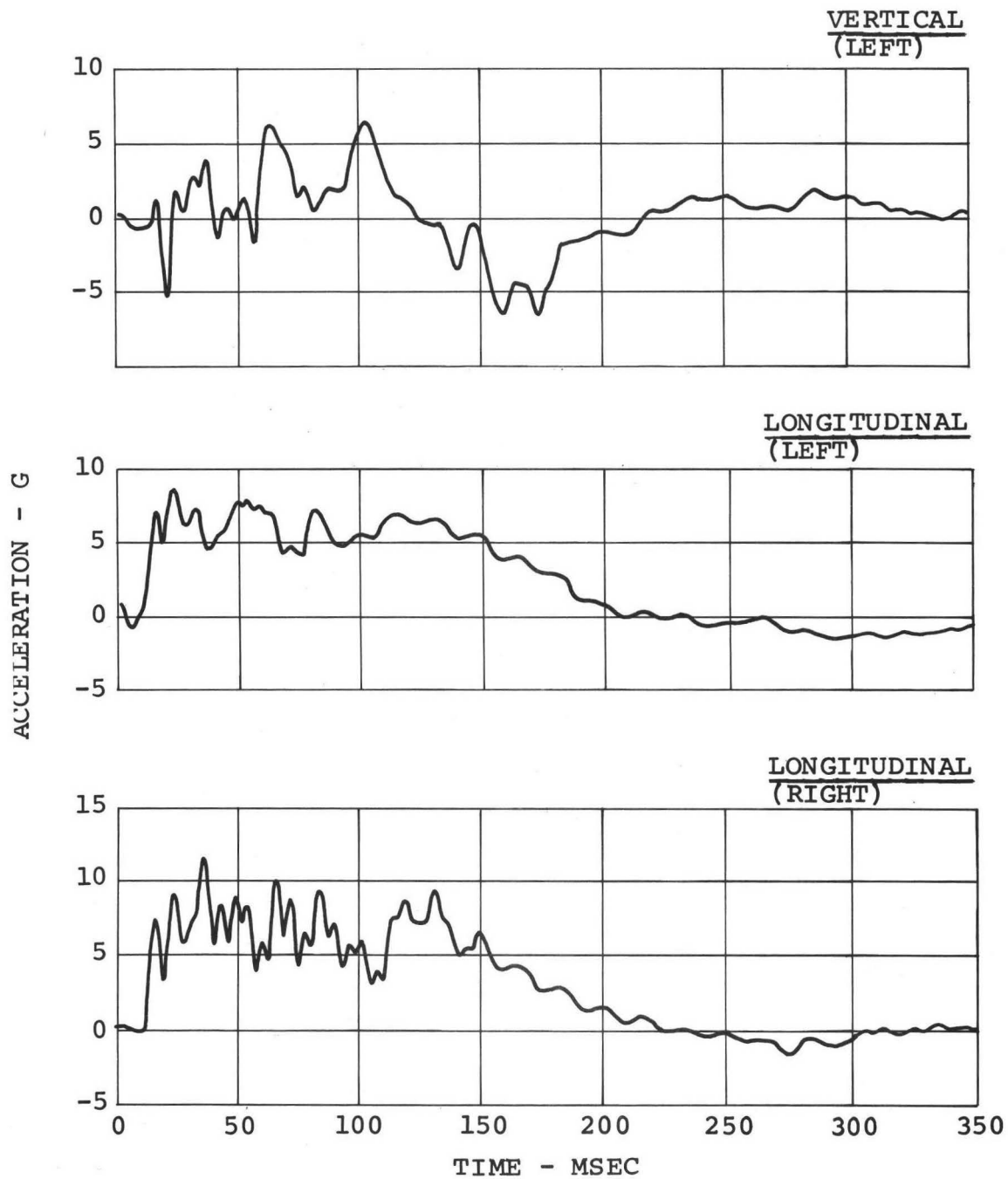


Figure G-25. Acceleration-Time Histories, Frame - AMC Ambassador.

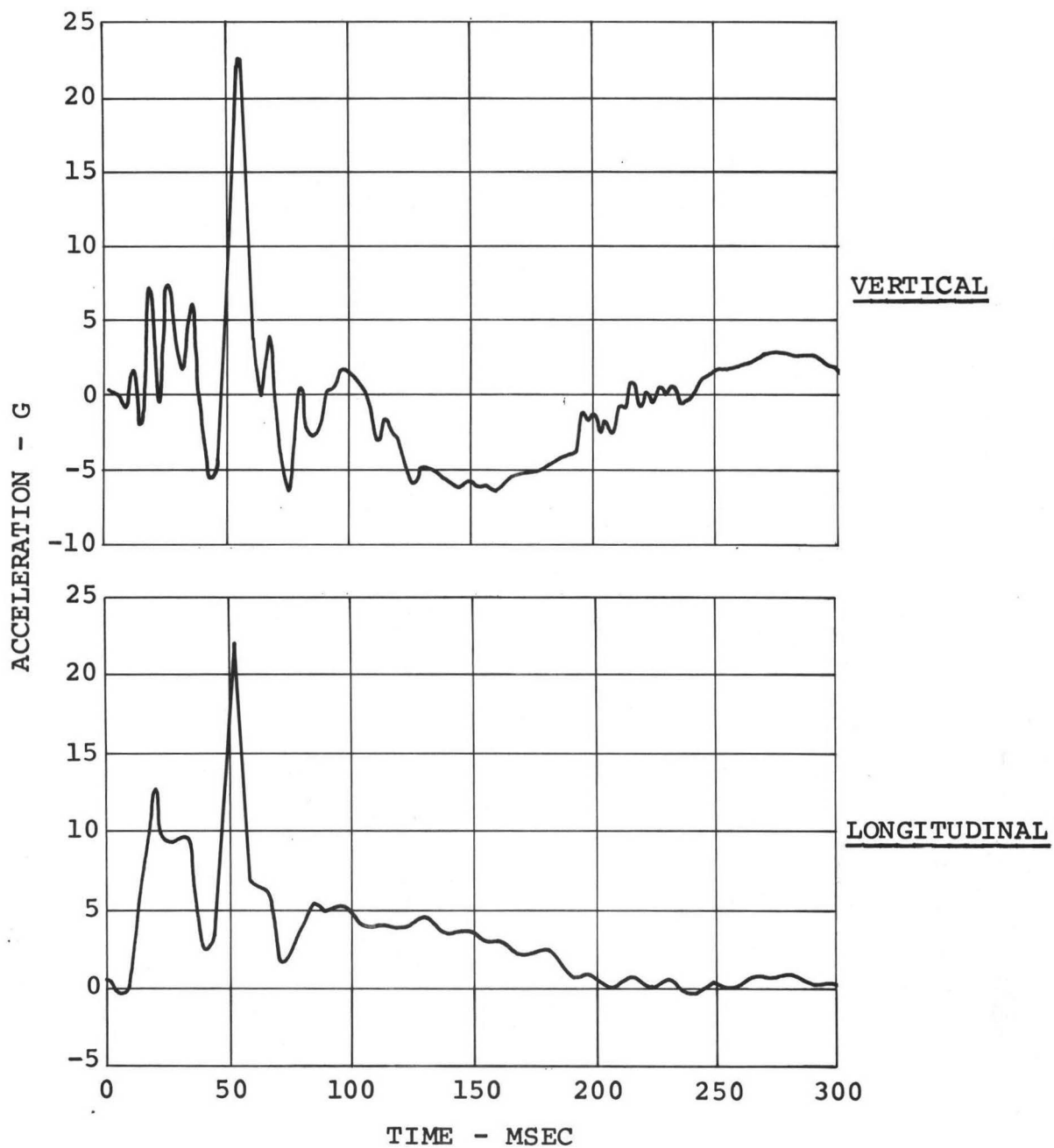


Figure G-26. Acceleration-Time Histories, Fuel Tank Area - AMC Ambassador.

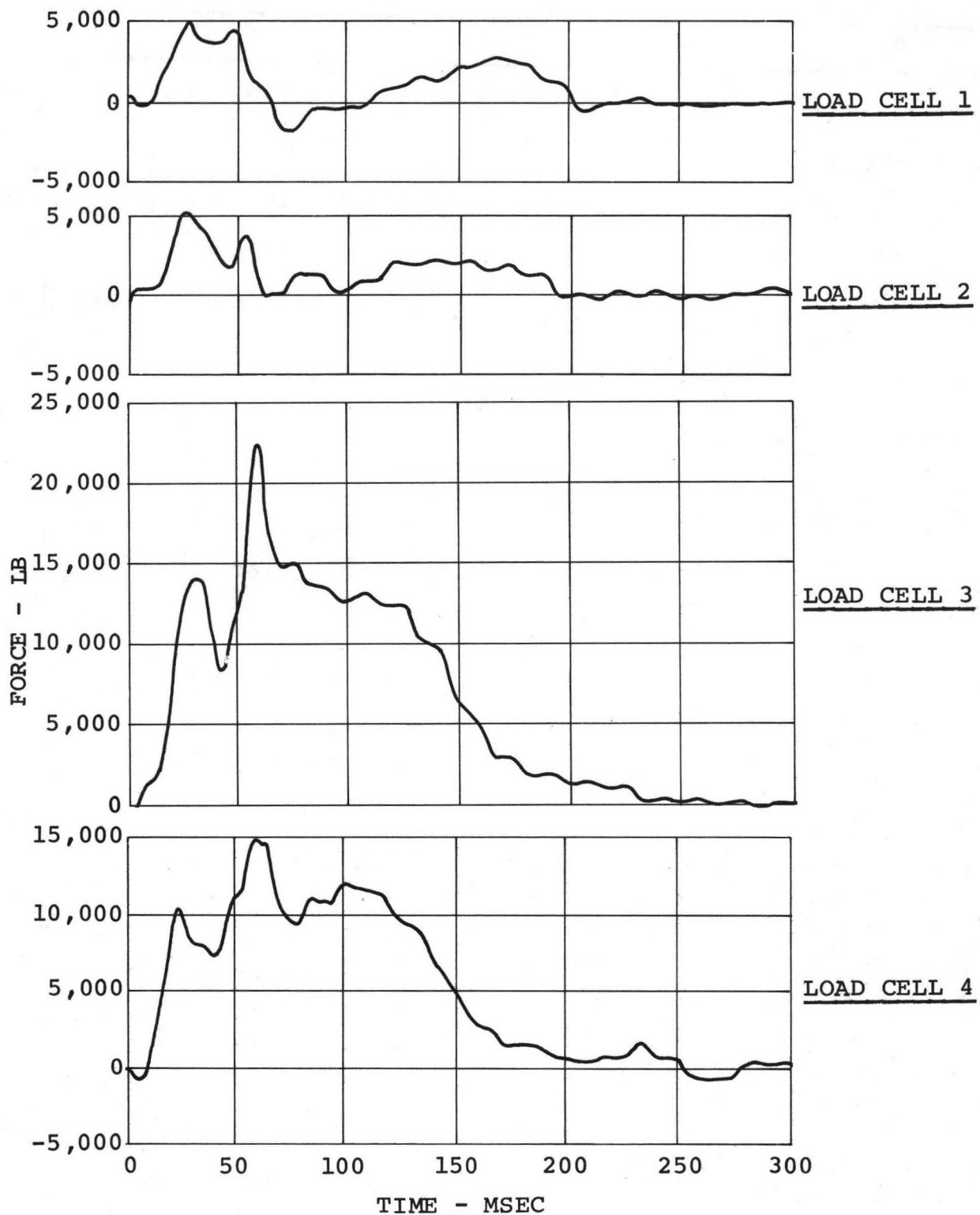


Figure G-27. Force-Time Histories, Barrier Load Cells - AMC Ambassador.

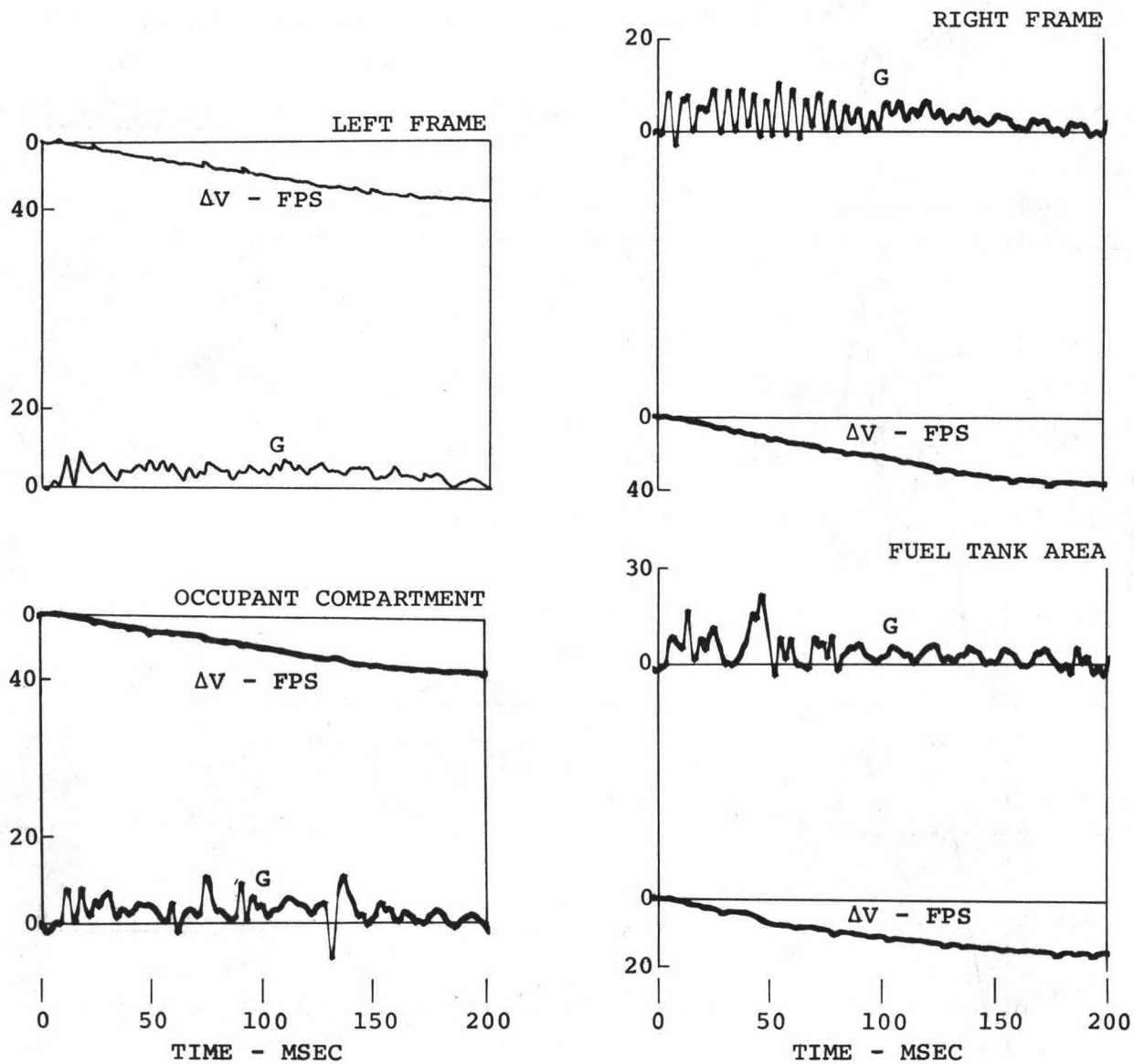


Figure G-28. Longitudinal Acceleration-Time Histories and Velocity Changes - AMC Ambassador.

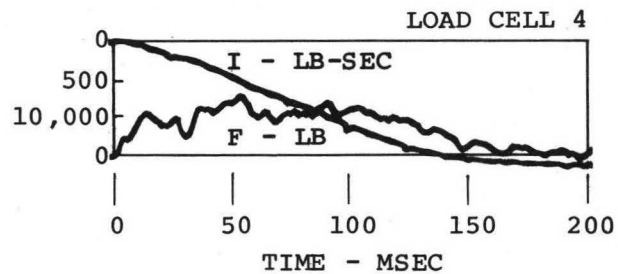
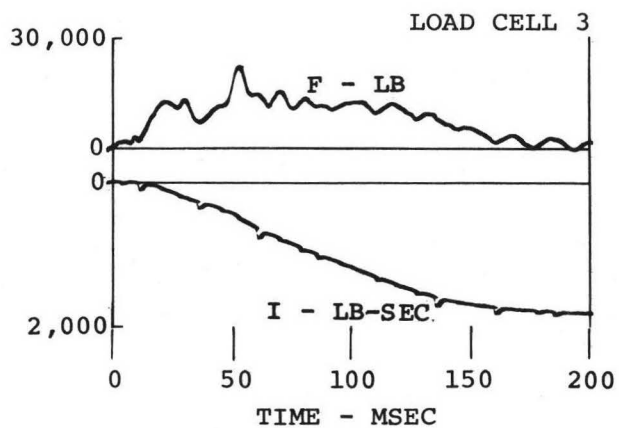
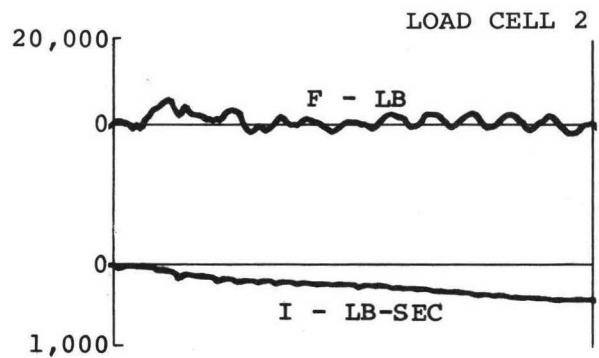
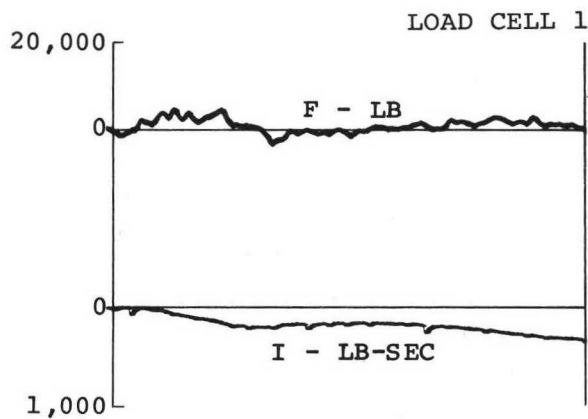


Figure G-29. Force-Time Histories and Impulses, Barrier Load Cells - AMC Ambassador.

G.4.5 Ford Pinto. Pre- and post-test views of the vehicle are shown in Figure G-30. The vehicle rebounded 17-1/4 inches from the barrier. Vehicle crushing was asymmetrical, with the right side of the vehicle crushing more than the left. The difference between the two sides was most pronounced behind the rear axle, but the difference was significant over the entire length of the body, as may be seen in Table G-III. (Dynamic crush on the right side of the vehicle was 18-1/2 inches. Dynamic crush on the left side could not be determined as no high-speed camera was located on this side of the vehicle.)

The crush differences are not surprising in view of the different reactions of each side of the vehicle to the impact. The right rear spring bent upward approximately 70 degrees at the rear of the car and also bent near the front spring hanger, as shown in the Pinto view in Figure 5-39. The left rear spring, however, bent very little and, as a result, the front spring hanger was pushed forward into the floor pan, tearing the structure at the front pan-rocker panel interface near the floor pan riser. This tear measured 8 inches in length.

The rear structure of the Pinto is not symmetrical. The spare tire is contained in a wheel well in the right side of the trunk floor. The irregularly shaped fuel tank is slung under the trunk floor, with the deep portion at the left beside the wheel well and the shallow portion underneath the left half of the wheel well. In addition, the major portion of the differential housing is located left of the centerline of the vehicle. The different reactions of the rear springs could have been due to the unsymmetrical rear structure of the vehicle or to differences in the spring stiffnesses and/or weld strengths in the structure, or to combinations of these factors.

Fluid spillage from the fuel tank resulted in a post-impact fire in the camera pit. This fire was quickly extinguished and no fire damage was incurred by the test vehicle. The high-speed film revealed that the leaking test fluid was ignited approximately 1 second after impact by the hot filament of a broken pit camera light.

Fluid spillage samples taken 6 to 8 minutes after impact established a minimum spillage rate of 18.1 oz/min. Post-test examination of the vehicle revealed that the right front part of the fuel tank had been struck by the differential housing, tearing two holes in the tank (see Figure 5-43). One hole was caused by a nut on the differential housing and the other by the edge of the housing adjacent to the nut.

The high-speed film showed that the differential first struck the tank in the right front center and then rotated upward into the tank as crushing continued, puncturing the tank at maximum crush and rotation. Dynamic crushing of the tank was evident



Figure G-30. Pre- and Post-test Views of Ford Pinto.

TABLE G-III. PERMANENT CRUSH DISTANCES OF FORD PINTO			
Measurement Location	Crush Distance (in.)		Crush Difference (in.)
Rear Bumper to:	Right Side	Left Side	
Near rear axle (rear 3 feet)	11-3/4	9	2-3/4
Near "B" pillar (rear 5 feet)	13	10-3/4	2-1/4
Near "A" pillar (rear 8 feet)	13	11-1/8	1/78

and measured 4-1/2 inches. Permanent crush was 3 inches. Tank deformation resulted in the tank bulging downward and also creasing at the right side where the punctures occurred.

The accelerometer and barrier load cell data are presented in Figures G-31 through G-35. Velocity change and impulse curves are presented in Figures G-36 and G-37.

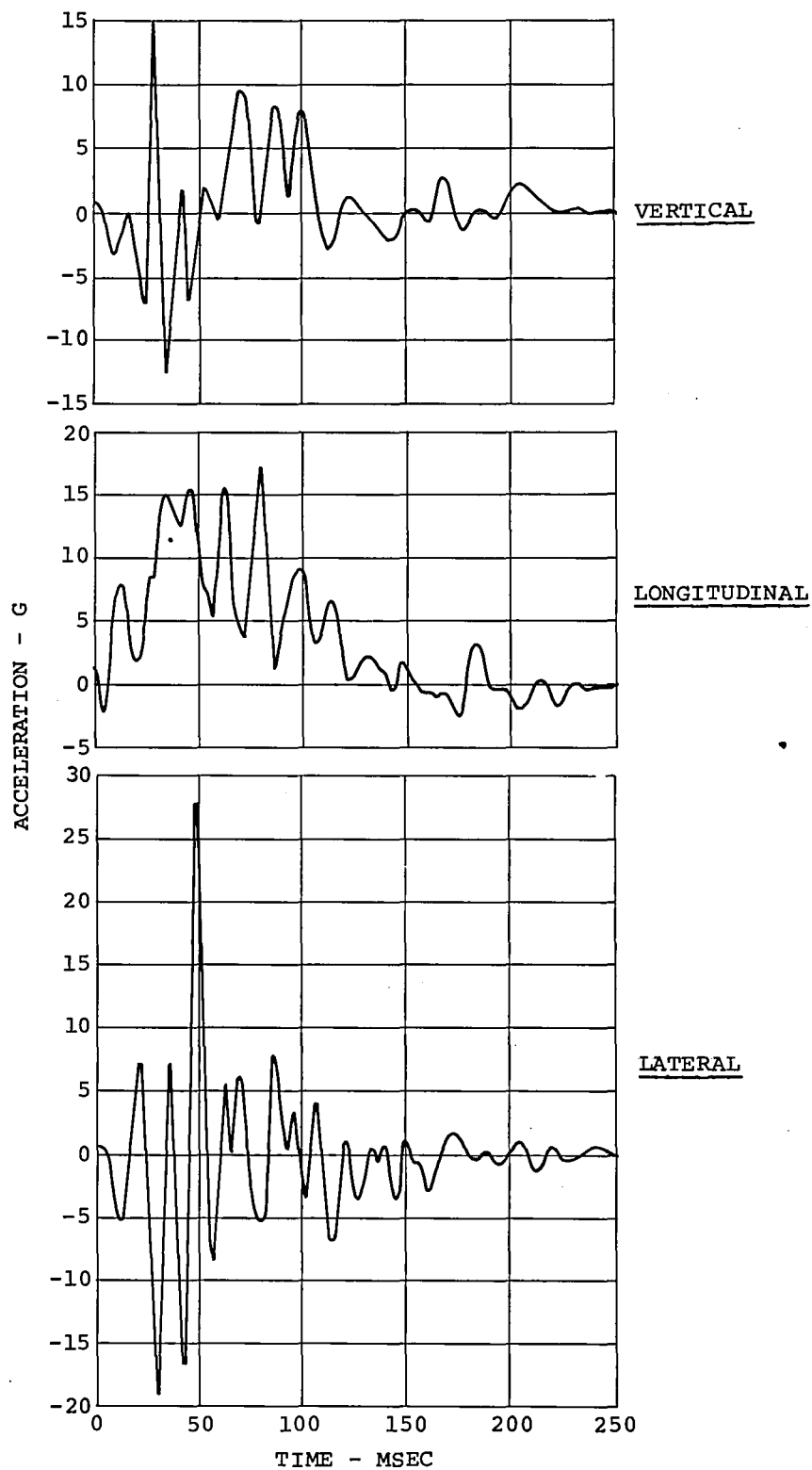


Figure G-31. Acceleration-Time Histories, Occupant Compartment - Ford Pinto.

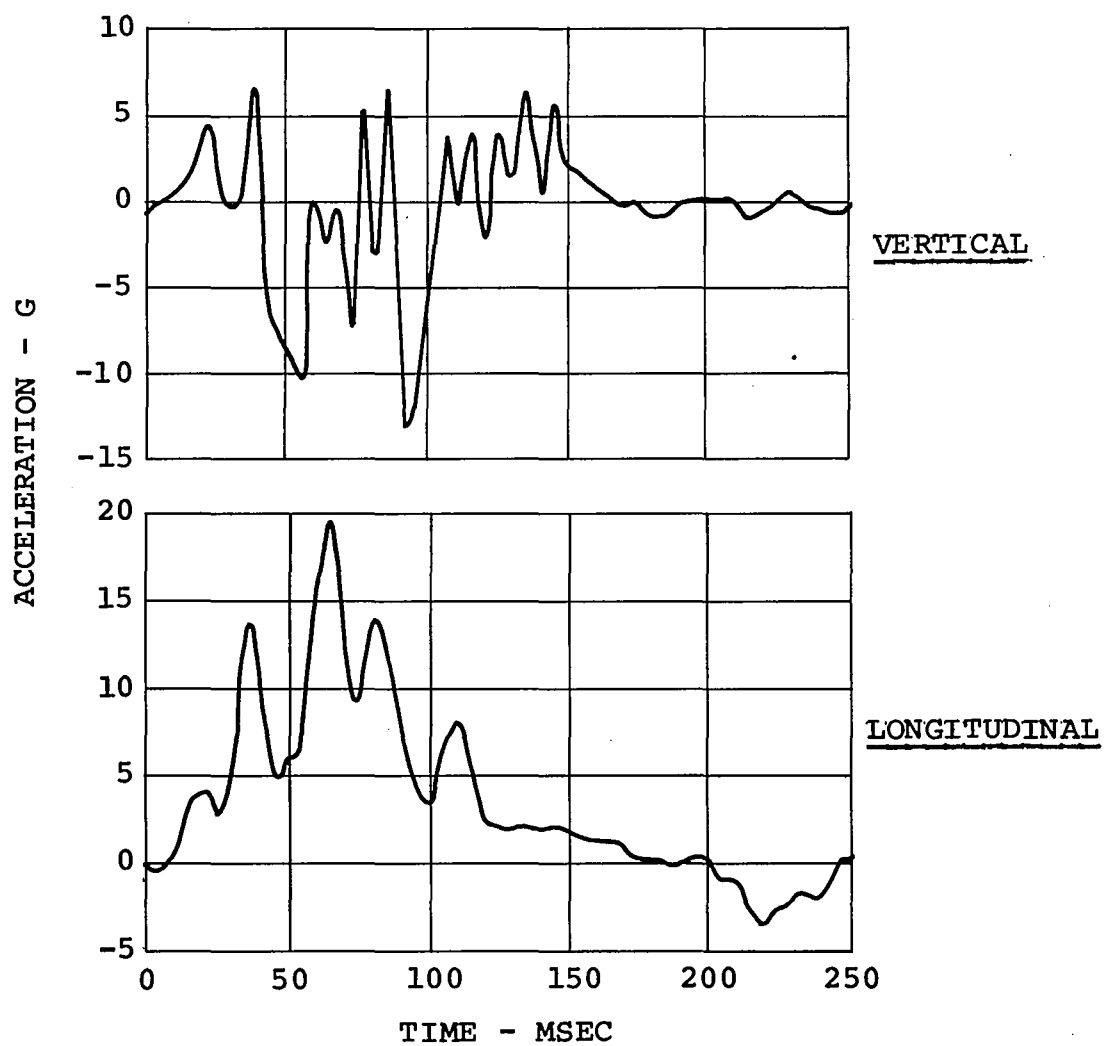


Figure G-32. Acceleration-Time Histories, Engine - Ford Pinto.

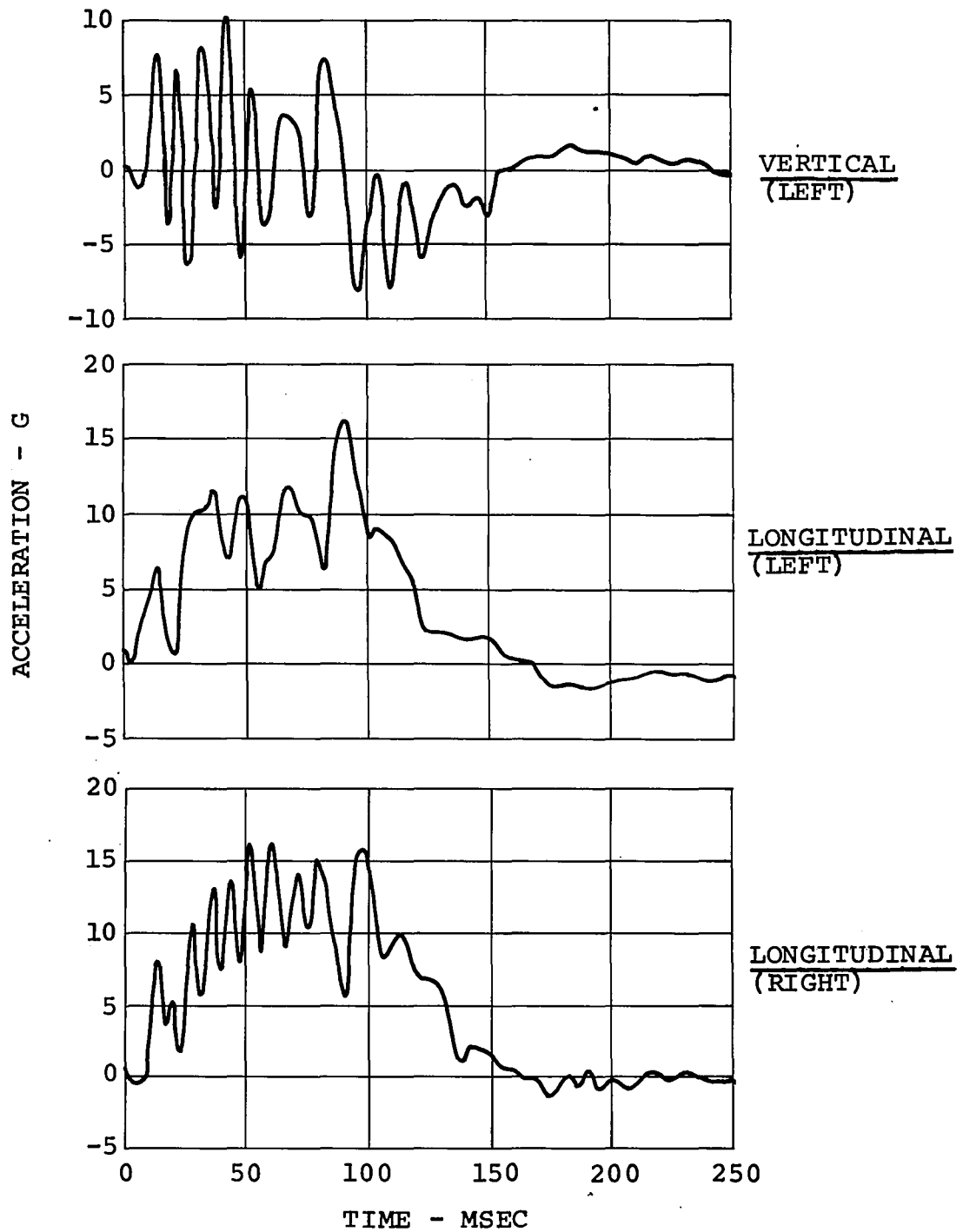


Figure G-33. Acceleration-Time Histories, Frame - Ford Pinto.

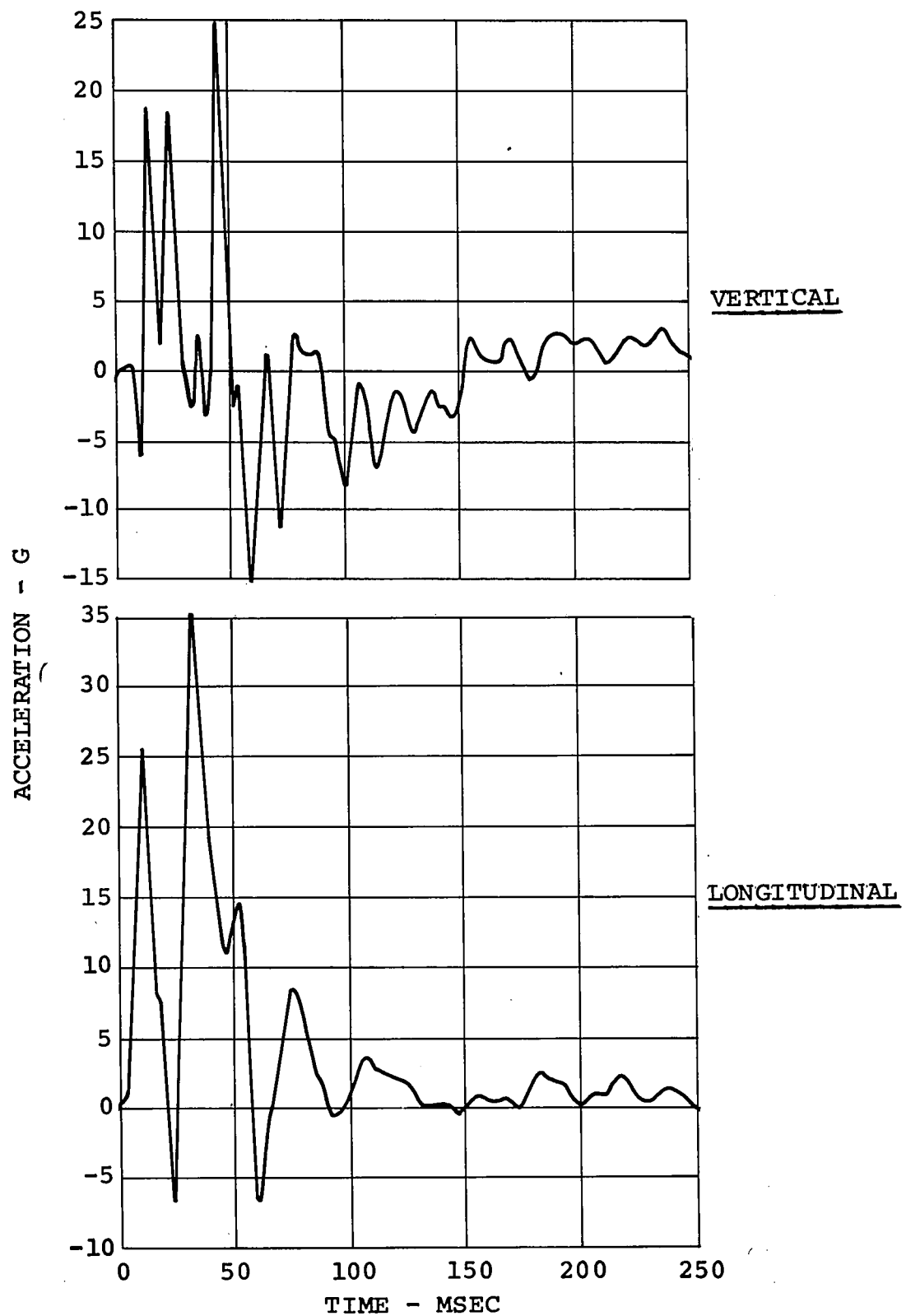


Figure G-34. Acceleration-Time Histories, Fuel Tank Area - Ford Pinto.

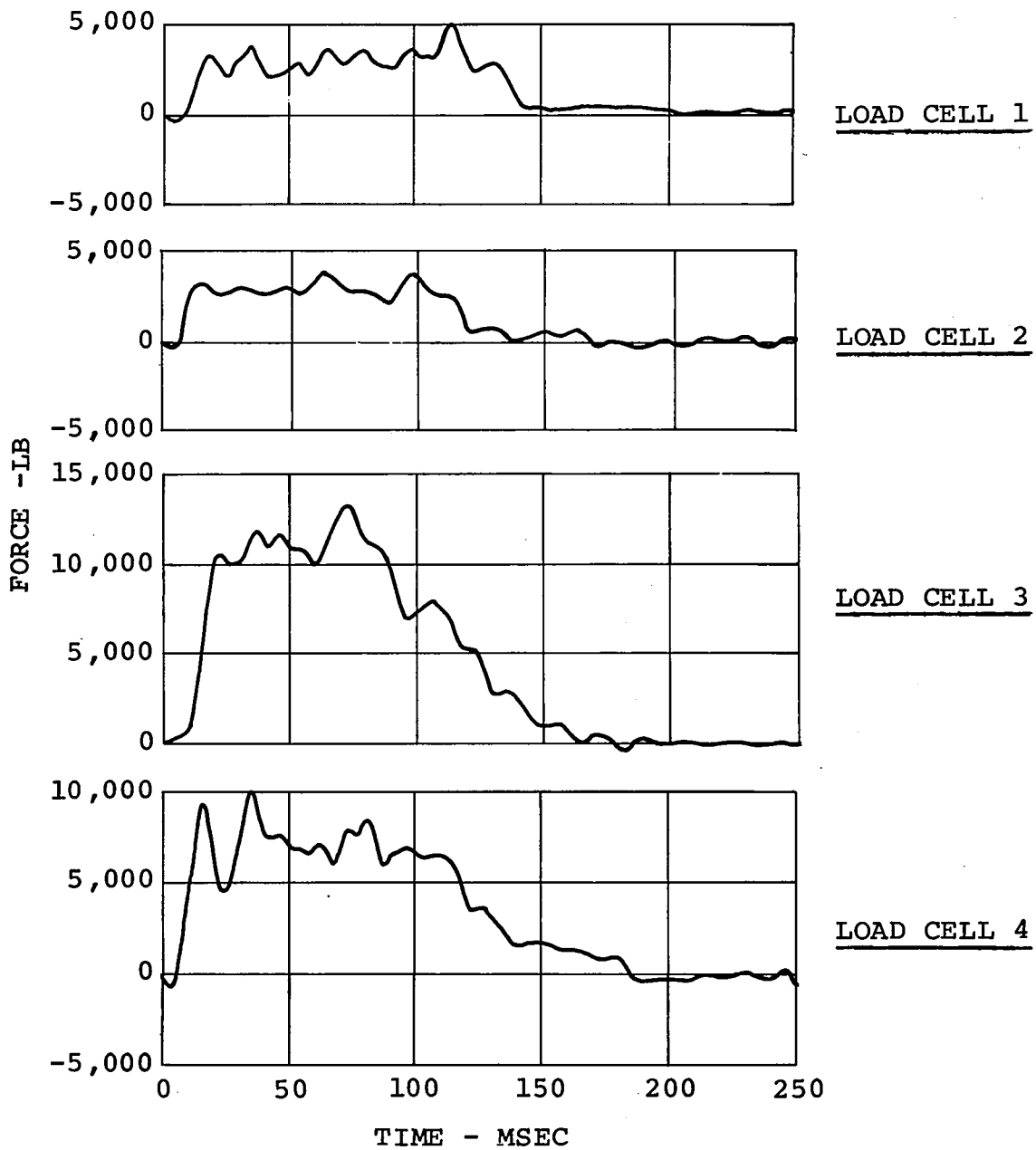


Figure G-35. Force-Time Histories, Barrier Load Cells - Ford Pinto.

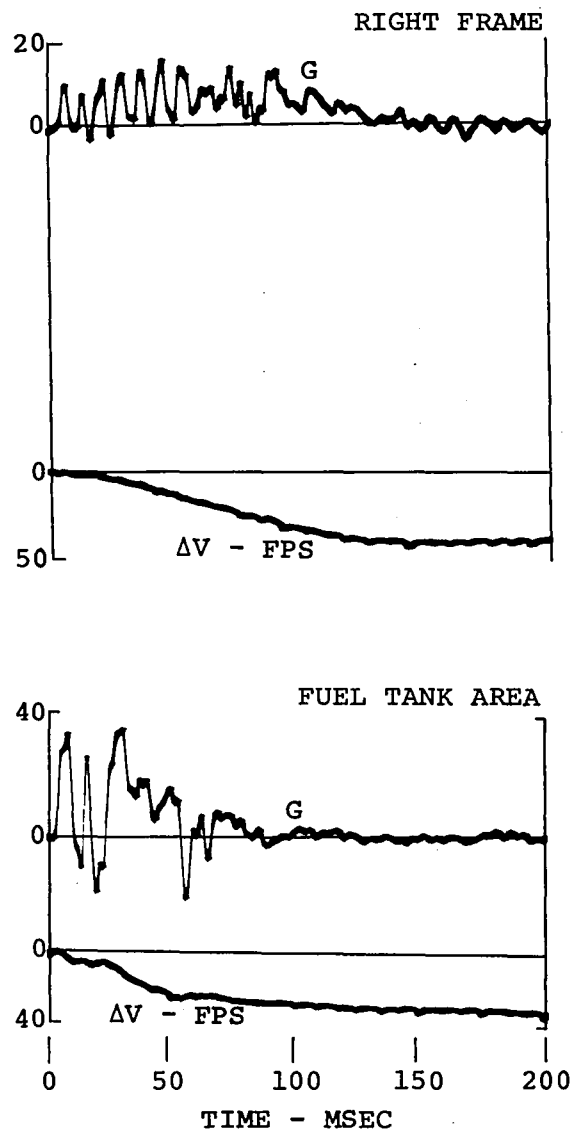
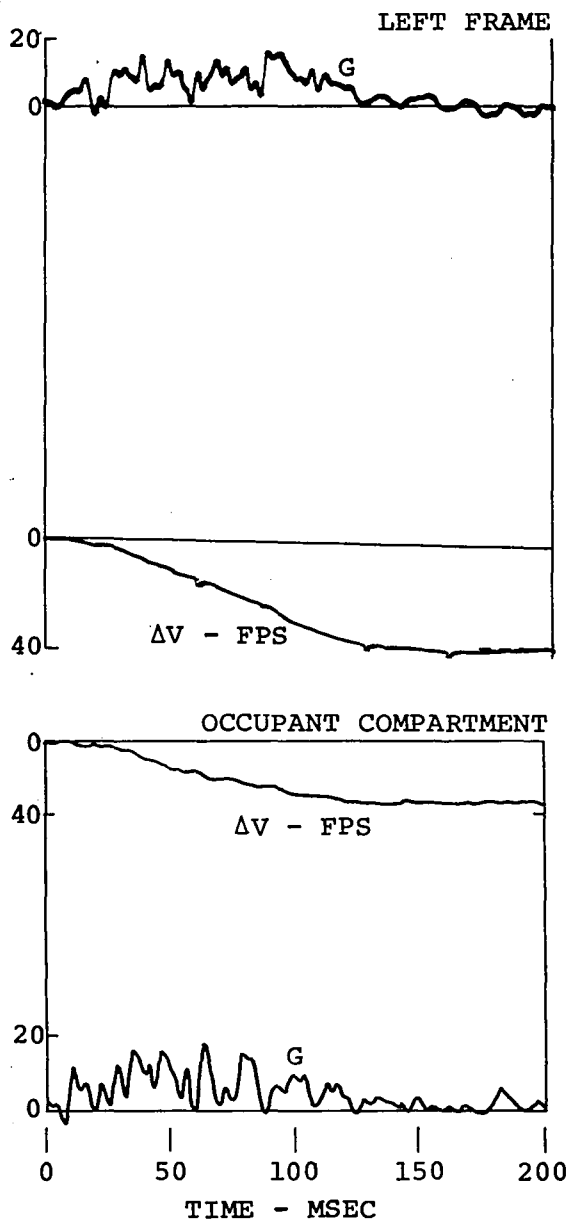


Figure G-36. Longitudinal Acceleration-Time Histories and Velocity Changes - Ford Pinto.

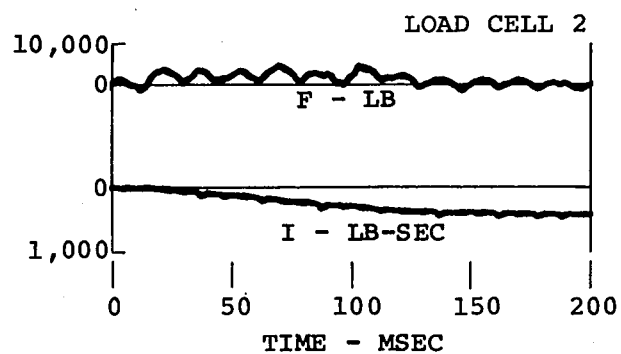
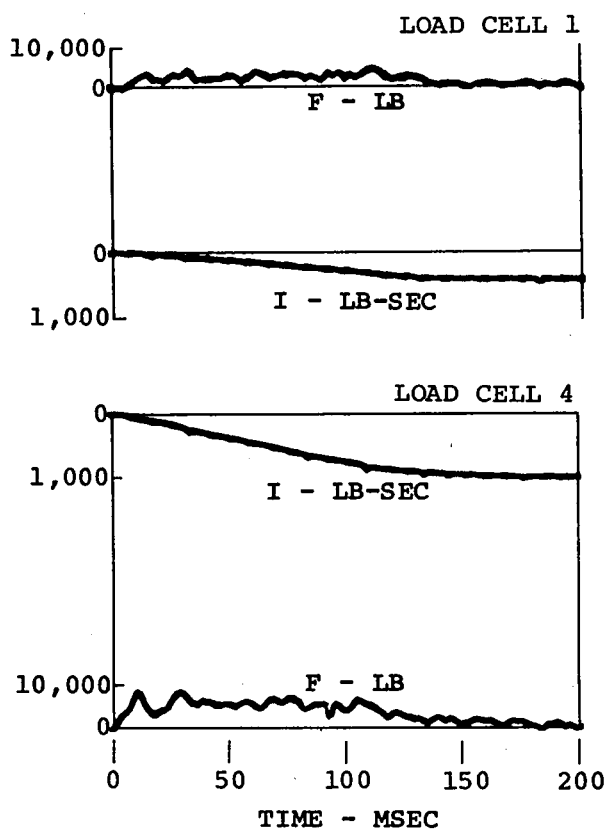


Figure G-37. Force-Time Histories and Impulses, Barrier Load Cells - Ford Pinto (No impulse trace available for Load Cell 3).

G.5 SUMMARY OF TEST DATA

Permanent and dynamic crush distances, as well as rebound distances, for all five vehicles are summarized in Table 5-II.

Peak accelerations for the Dodge station wagon, Chevelle, Ambassador, and Pinto are summarized in Table 5-III. Maximum velocity changes at various points on the vehicles were obtained by integrating the acceleration-time traces at these locations. These data are summarized in Table G-IV. These velocity changes are greater than the vehicle impact velocity since they include the rebound velocity.

TABLE G-IV. TOTAL VELOCITY CHANGE DURING REAR IMPACT BARRIER TESTS				
Accelerometer Location	ΔV (mph)			
	Dodge	Chevelle	Ambassador	Pinto
Right Frame	35.2	25.4	23.5	26.7
Left Frame	33.6	23.7	24.7	25.4
Fuel Tank Area	30.3	23.4	22.9	23.4
Occupant Compartment	32.0	23.7	22.0	23.2

The impulses received by the vehicles from the barrier are summarized in Table G-V. Impulse was obtained by integrating the force versus time data recorded on the barrier load cells. The total impulse for the AMC Ambassador appears to be 5-10 percent lower than would be consistent with the total velocity change. This may be due to the fact that the front end damage incurred in the prior front end crash caused some binding under the high front end vertical loads between 75-100 msec, restricting the free rotation of the front wheels.

TABLE G-V. BARRIER IMPULSE DURING REAR IMPACT
BARRIER TESTS

Load Cell No.	Load Cell Location	Impulse (lb-sec)			
		Dodge	Chevelle	Ambassador	Pinto
1	Top - South	1674	553	311	484
2	Top - North	1620	363	379	389
3	Bottom - North	2427*	1800	1814	1085*
4	Bottom - South	2186	1669	1531	964
	Total	7907	4385	4035	2922
*Derived from manual integration - no impulse trace available.					

SPU 925-853