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AUTOMOBILE ENGINE CONTROL PARAMETERS STUDY

VOLUME I: SUMMARY AND STATUS OF DOMESTIC ENGINE CONTROL PRACTICES

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16. Abstract

This report contains the results of a study to evaluate automobile engine control parameters and their effects on vehicle fuel economy and emissions.

Volume I presents detailed technical information on the engine control practices used by selected domestic vehicle manufacturers to meet past and current emission standards, and their own fuel economy, performance and driveability objectives. Volume II treats selected foreign manufacturers. The principal topics reviewed for the twenty-eight engines selected for study are engine design modifications, intake system, carburetion, ignition system, emission control devices and fuel economy effects.

Also included is a discussion of the operational characteristics and design features of engine control hardware, systems, and techniques, and their general implications on fuel economy and emissions.

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PREFACE

This report, prepared by The Aerospace Corporation for the U.S. Department of Transportation, Transportation Systems Center, summarizes the results of an evaluation of automobile engine control parameters and their effects on vehicle fuel economy and emissions. The technical base for this assessment is derived from a comprehensive review of current information on automobile engine operation and performance.

A total of 28 domestic and foreign spark ignition automobile engines in the 40 to 150 horsepower output range were examined in this study, covering the time period from early emission control years through the 1976 model year. The control devices and techniques examined include engine modifications, carburetor, fuel injection, intake system, ignition system, exhaust gas recirculation, and exhaust aftertreatment.

This report is organized in two volumes. This volume, Volume I, provides a brief synopsis of study findings, highlighting the significant features and effects of each control technique examined. In addition, it presents (1) a review of the design features and operational characteristics of the engine control approaches employed by the domestic and foreign automobile industry, and (2) a detailed examination of the control techniques incorporated in the selected domestic engines, with particular emphasis on the effects of control system modifications on vehicle fuel economy and emissions.

Volume II provides a detailed characterization of the control approaches used in the selected foreign engines.

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The following technical personnel of The Aerospace Corporation contributed to the effort performed under this contract.

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A. Muraszew

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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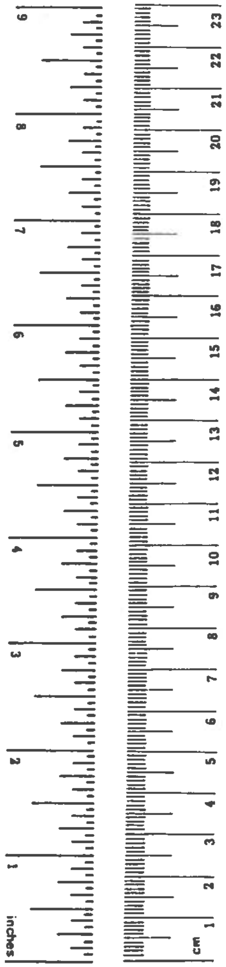
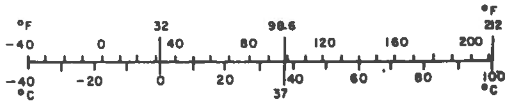
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

Volume II

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

LIST OF SYMBOLS AND ABBREVIATIONS

A	automatic transmission
AAP	auxiliary acceleration pump
AAPS	Advanced Automotive Power Systems
ABC	after bottom center
ABPV	air bypass valve
A/C	air conditioning
ACV	air control valve
AEEP	Automotive Energy Efficiency Program (DOT)
A/F	air/fuel ratio
AIC	automatic idle control
AIR	air injection reactor
AMC	American Motors Corporation
ASV	air switching valve
ATC	after top center
AVSAC	automatic vehicle speed spark advance control
BBC	before bottom center
BCDV	boost-controlled deceleration valve
BID	breakerless inductive discharge
BPS	backpressure sensor
BTC	before top center
CAIR	converter air injection reactor
CAP	clean air package
CAT	catalyst
CCSA	coolant-controlled spark advance
CCEGR	coolant-controlled exhaust gas recirculation
CCIE	coolant-controlled idle enrichment
CCS	Controlled Combustion System
CCV	closed crankcase ventilation
cfm	cubic feet per minute
CID	cubic inch displacement
CIS	continuous injection system
CO	carbon monoxide

COP	choke opener
COS	cutoff switch
CR	compression ratio
CTO	coolant temperature override
CWS	catalyst warning system
DOT	Department of Transportation
DVDV	differential valve delay valve
EARV	emergency air relief valve
EFE	early fuel evaporation
EGR	exhaust gas recirculation
EM	engine modification
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
ESA	electronic spark advance
EVAP	evaporative control system
FDV	fuel deceleration valve
FI	fuel injection
FTP	Federal Test Procedure
GM	General Motors Corporation
HC	hydrocarbon
HEI	high energy ignition
Hg	mercury
IMCO	improved combustion emission control
LTR	lean thermal reactor
M	manual transmission
MC	mixture control
mpg	miles per gallon
NA	not available
NO_x	oxides of nitrogen
OD	overdrive
OHC	overhead cam
OHV	overhead valve

ORI	octane requirement increase
OSAC	orifice spark advance control
PCV	positive crankcase ventilation
PO	pulloff (switch)
PVS	ported vacuum system
rpm	revolutions per minute
RTR	rich thermal reactor
SDV	spark delay valve
TAV	temperature-activated vacuum
TCS	transmission controlled spark
TIDC	thermostatic ignition distributor vacuum control
TIV	thermactor idle dump valve
TOCS	throttle opener control system
TR	thermal reactor
TSP	throttle solenoid positioner
TSC	Transportation Systems Center (DOT)
TVS	thermal vacuum switch
TVSV	thermo-vacuum switch valve
V	venturi
VDV	vacuum differential valve
VSV	vacuum switching valve
VTV	vacuum transmitting valve
WOT	wide open throttle

EXECUTIVE SUMMARY

1. INTRODUCTION AND SCOPE

This report, prepared by The Aerospace Corporation for the U. S. Department of Transportation, Transportation Systems Center, presents the results of a study conducted to survey and evaluate the engine control practices used by selected domestic and foreign automobile manufacturers in current and earlier model year engines. In the main body of the report, descriptions of control systems used with specific engine designs are provided. Also, an evaluation of each system is presented by correlating year-to-year changes in controllable engine parameters with changes in vehicle performance. Performance measures used are primarily fuel economy and exhaust emissions although more subjective aspects of performance, such as driveability, are also considered. The work accomplished in the study involves conventional spark ignition engines, and addresses engine control practices incorporated through basic internal engine design as well as by the addition of control systems external to the engine. Control practices are examined at the system, the subsystem, and the individual control device levels.

To provide a historical perspective for the assessment of engine control practices within the constraints allowed by the availability of data and the chronological continuity of individual engine designs, the study covers a time period from pre-emission, or early emission control years through the 1976 model year. To limit the scope of the study, engine control systems are not examined for every model year in the subject time period. Instead, only the last three model years and those earlier years in which significant changes in exhaust emission standards have occurred are selected. This approach is based on the rationale that exhaust emission standards represent a major constraint and, therefore, act as a prime determinant for changes in engine control system design.

2. ENGINE CONTROL SYSTEMS OVERVIEW

The methods of engine control used over the past several years have been strongly influenced by the need to limit exhaust emissions. This leads to a natural characterization of engine control methods according to the manner in which exhaust emissions are controlled. With this in mind, Tables 1 and 2 present summaries of engine control systems used by the various manufacturers to meet respective 49-states and California exhaust emission control requirements for the 1974 through 1976 model years. This three-year span is of special interest because it embraces the introduction and widespread application of oxidation catalysts, which afford an opportunity for the first extensive shift in the burden of hydrocarbon (HC) and carbon monoxide (CO) emission control from the engine to a system external to the engine. In effect, the use of a catalytic exhaust emission control system represents a basic change in the philosophy of engine controls used in earlier model years.

Each emission control system/technique listed in Tables 1 and 2 controls one or more of the three currently regulated exhaust emission species, HC, CO, and oxides of nitrogen (NO_x), and may have a positive, negative, or neutral impact on fuel economy. The following section elaborates on each of these control systems, discusses its impact on vehicle performance, and points out distinctive attributes of the systems implemented by individual manufacturers.

3. ENGINE CONTROL SYSTEMS

3.1 Engine Modifications

Changes made to the basic engine such as reconfiguration of the combustion chamber or a change in valve timing are examples of engine modifications discussed in this section. Changes in systems such as the distributor or fuel-delivery system, are considered as modifications to an individual component or system and are treated in separate subsections.

3.1.1 Combustion Chamber Configuration

The combustion chamber configuration of a spark ignition engine impacts fuel economy, driveability, and exhaust emission performance. The combustion chamber shape and the location of the valves affect the flow pattern, the degree of turbulence, the heat transfer to the wall, and consequently, the speed of flame propagation and the thickness of the wall boundary layer. In general, intensive turbulence tends to increase the formation of NO_x and HC. In the case of NO_x, this occurs because of the higher peak

TABLE 1. ENGINE EMISSION CONTROL SYSTEMS OVERVIEW: 49-STATES APPLICATIONS

Manufacturer	CID	Model Year Control System Type[a,b]																		
		1976							1975							1974				
		FI	Oxidizing Catalyst	TR	Secondary Air	EGR	Modified Spark Advance	Modified Valve Overlap	FI	Oxidizing Catalyst	TR	Secondary Air	EGR	Modified Spark Advance	Modified Valve Overlap	FI	Secondary Air	EGR	Modified Spark Advance	Modified Valve Overlap
AMC	232				x[c]	x	x	x		x[c]		x[c]	x	x	x		x[c]	x[c]	x	x
	258		x[c]		x[c]	x	x	x		x[c]		x[c]	x	x	x		x[c]	x[c]	x	x
	304		x		x	x	x	x		x		x	x	x	x		x[c]	x	x	x
Chrysler	225		x			x	x	x		x			x	x	x			x	x	x
	318		x[d]		x[d]	x	x	x		x[d]		x[d]	x	x	x			x	x	x
Ford	140		x		x	x	x	x				x	x	x	x		x	x	x	x
	171		x		x	x	x	x		x		x	x	x	x		x	x	x	x
	250		x		x	x	x	x		x		x	x	x	x			x	x	x
	351		x		x	x	x	x		x		x	x	x	x			x	x	x
GM	140		x[d]		x[d]	x	x	x		x[d]		x[d]	x	x	x			x	x	x
	250		x			x	x	x		x			x	x	x		x[c]	x	x	x
	350		x			x	x	x		x		x[c]	x	x	x		x[c]	x	x	x
Audi	97	x				x[c]	x	x	x			x[c]	x	x	x					
	114	x				x	x	x	x			x[c]	x	x	x		x	x	x	x
BMW	121				x		x	x			x	x	x	x	x	x[c]		x[c]	x	x
British Leyland	91				x	x	x	x				x	x	x	x			x	x	x
	110		x		x	x	x	x				x	x	x	x		x		x	x
Fiat	79		x[c]		x		x	x		x[d]		x		x	x		x		x	x
Mercedes Benz	168		x		x	x	x	x		x		x	x	x	x			x	x	x
Nissan	85				x	x	x	x				x	x	x	x					
	119				x	x	x	x				x	x	x	x		x	x	x	x
Peugeot	120			x	x		x	x			x	x		x	x		x		x	x
Saab	121	x				x[c]	x	x	x				x[c]	x	x	x[c]			x	x
Toyota	97				x		x	x				x		x	x				x	x
	134				x	x	x	x				x	x	x	x					
VW	96	x				x	x	x	x				x	x	x			x	x	x
	97	x[c]	x		x	x	x	x				x		x	x			x	x	x
Volvo	121	Replaced with new design							x			x	x	x	x	x		x	x	x

[a] x indicates system is used in model year shown

[b] FI = fuel injection; TR = thermal reactor

[c] Not all models

[d] Catalyst or AIR

TABLE 2. ENGINE EMISSION CONTROL SYSTEMS OVERVIEW: CALIFORNIA APPLICATIONS

Manufacturer	CID	Model Year Control System Type[a,b]																		
		1976							1975							1974				
		FI	Oxidizing Catalyst	TR	Secondary Air	EGR	Modified Spark Advance	Modified Valve Overlap	FI	Oxidizing Catalyst	TR	Secondary Air	EGR	Modified Spark Advance	Modified Valve Overlap	FI	Secondary Air	EGR	Modified Spark Advance	Modified Valve Overlap
AMC	232		x		x	x	x	x		x		x	x	x	x			x	x	x
	258		x		x	x	x	x		x		x	x	x	x		x[c]	x	x	x
	304		x		x	x	x	x		x		x	x	x	x		x	x	x	x
Chrysler	225		x		x	x	x	x		x		x	x	x	x			x	x	x
	318		x		x	x	x	x		x		x	x	x	x			x	x	x
Ford	140		x		x	x	x	x		x		x	x	x	x		x	x	x	x
	171		x		x	x	x	x		x		x	x	x	x		x	x	x	x
	250		x		x	x	x	x		x		x	x	x	x		x	x	x	x
	351		x		x	x	x	x		x		x	x	x	x			x	x	x
GM	140		x		x	x	x	x		x		x	x	x	x			x	x	x
	250		x		x	x	x	x		x		x	x	x	x		x	x	x	x
	350		x		x	x	x	x		x		x	x	x	x		x	x	x	x
Audi	97	x	x			x	x	x	x	x			x	x	x					
	114	x	x			x	x	x	x	x			x	x	x		x	x	x	x
BMW	121			x	x	x	x	x			x	x	x	x	x	x[c]		x[c]	x	x
British Leyland	91		x		x	x	x	x		x		x	x	x	x			x	x	x
	110		x		x	x	x	x		x		x	x	x	x		x		x	x
Fiat	79		x		x		x	x		x		x		x	x		x		x	x
Mercedes Benz	168		x		x	x	x	x		x		x	x	x	x			x	x	x
Nissan	85		x		x	x	x	x		x		x	x	x	x					
	119		x		x	x	x	x		x		x	x	x	x		x	x	x	x
Peugeot	120			x	x		x	x			x	x		x	x		x		x	x
Saab	121	x			x	x	x	x	x			x	x	x	x	x[c]			x	x
Toyota	97		x		x		x	x		x		x		x	x		x		x	x
	134		x		x	x	x	x		x		x	x	x	x					
VW	96	x	x			x	x	x	x	x			x	x	x			x	x	x
	97	x[c]	x		x	x	x	x		x		x	x	x	x			x	x	x
Volvo	121	Replaced with new design							x	x		x	x	x	x	x		x	x	x

[a] x indicates system is used in model year shown

[b] FI = fuel injection; TR = thermal reactor

[c] Not all models

combustion temperature associated with turbulence. For HC, the decrease in the selective retention of HC rich boundary layer gases causes the increase in emissions.

In general, NO_x formation decreases with increasing combustion chamber surface-to-volume ratio as a direct result of increased cooling of the combustion gases near the cylinder walls. However, this is accompanied by an increase in the size of the wall quench layer and an attendant increase in the formation of HC. This interrelationship presents an opportunity for a tradeoff of HC and NO_x emissions control in combustion chamber design, which is most often resolved in favor of limiting the formation of HC. Control of NO_x is then implemented by using intake charge dilution achieved via modified intake-exhaust valve overlap or exhaust gas recirculation (EGR).

The combustion chamber surface-to-volume ratio tends to increase rapidly with decreasing displacement. For the engines evaluated in this study, this trend is exemplified by the Fiat engine, which has both the smallest displacement (79 CID) and the largest surface-to-volume ratio (11.06 sq in. /cu in.) of all engines listed in Tables 1 and 2. On the opposite end of the scale, the large displacement domestic engines typically exhibit surface-to-volume ratios between 6 sq in/cu in. and 7 sq in. /cu in.

To achieve knock-free engine operation with unleaded gasoline, the engine compression ratio has been lowered in recent years from above 9 to about 8 at the expense of a small loss in fuel economy. Typically, a reduction in compression ratio from 9 to 8 decreases fuel economy by from 3 to 5 percent. While this reduction is not as large as the loss in fuel economy associated with some of the engine emission control methods discussed in other sections, it does have a distinct and measurable negative impact.

3.1.2 Valve Timing

Without consideration of exhaust emissions, intake and exhaust valve timing schedules would be selected to provide the best volumetric efficiency over the expected engine operating range. However, promulgation of exhaust emission standards has, in many cases, forced departures from optimum schedules to increase charge dilution in the interest of lowering NO_x and HC emissions.

Recent examples of valve-timing modifications are often associated with the introduction of EGR. Before the widespread application of EGR, intake charge dilution for purposes of NO_x control was achieved by relatively high levels of intake-exhaust valve overlap. As NO_x reduction is relatively insensitive to the manner in which charge dilution is obtained, the utilization of EGR allows a decrease in valve overlap. An example is offered by the introduction of EGR on the American Motors (AMC) 1974 model 232-CID engine. For that model year, one version of this engine is equipped with EGR and a valve overlap of 38 degrees, while the non-EGR version of the same engine exhibits a valve overlap of 68 degrees. The additional overlap of the non-EGR engine is obtained entirely by delayed exhaust valve closing, which has been shown to be primarily a NO_x abatement technique rather than a method of HC control.

An example of the magnitude of the increase in valve overlap between pre-emission and recent emission control years is afforded by the Chrysler 225-CID engine. In 1967, the subject engine has a valve overlap of 16 degrees, while the 1976 version with EGR uses 26 degrees. This is typical of the approach selected by many manufacturers to achieve a balance among valve overlap, other emission control methods, and overall vehicle performance.

In general, the use of valve overlap as an emission control technique degrades the low-speed torque and idle characteristics of the engine. For that reason, valve overlap is no longer used as a principal NO_x control method.

3.2 Intake System

An engine's intake system provides the basic function of delivering a combustible air/fuel charge to each cylinder. For the engines assessed in this report, either a carburetor or a fuel injection delivery system is used. In each of these systems, the intake delivers filtered air to a point at which air and fuel are mixed. For carburetor-based systems mixing takes place at a single point remote from the cylinders (i. e., at the carburetor), while in manifold injection systems the mixture is prepared in the intake manifold immediately adjacent to each cylinder. The air/fuel mixture thus travels a much shorter distance to the combustion chamber in the fuel injection system than it does in the carburetor-based system. It is this dissimilarity in distance which gives rise to a number of design variations between carburetor and fuel injection intake systems.

One of the important design objectives in carburetor-based fuel systems is the enhancement of fuel vaporization. This is particularly important because engine performance and emission characteristics depend on a uniform cylinder-to-cylinder air/fuel mixture distribution which, in turn, requires nearly complete vaporization of the fuel at the carburetor.

In current carburetor-based systems, fuel vaporization is usually aided by preheating and thermostatically controlling intake air. In these systems, heat from the exhaust manifold is used to warm underhood air. The heated air is then mixed with ambient underhood air in proportions controlled by a flap valve situated in the snorkel of the air cleaner. Flapper valve position is controlled by a sensor, which monitors the temperature of the mixture of ambient and warmed air, and by a vacuum motor connected to the flap valve. Typical inlet air temperatures are near 100°F.

Many domestic and foreign automobile manufacturers also currently employ thermostatically controlled exhaust gas heat riser systems on carburetor-equipped engines. During engine warmup, these systems route hot exhaust gases through passages in the intake manifold, thereby transferring exhaust gas heat to the intake charge. Although these systems have been used for many years, some refinements have recently been incorporated to increase their efficiency. For example, on the Chrysler 318-CID engine, the use of closer manufacturing tolerances has permitted a reduction in the thickness of the intake manifold floor, resulting in improved heat transfer from the exhaust gas to the intake charge.

On the AMC 232- and 258-CID engines, a stainless steel "hot spot" in the intake manifold beneath the carburetor fulfills the same function. The Chevrolet 250-CID 6-cylinder engine uses an integrally cast cylinder head and intake manifold to implement early fuel evaporation (EFE) on many recent models.

Exhaust gas heat riser or thermostatically controlled air inlet systems are generally not used on engines with fuel injection. However, time-modulated fuel injection systems often rely on an air temperature sensor in the intake system to provide an input to the fuel injection control module, which uses air temperature as one of the variables to determine the amount of fuel to be injected into each cylinder intake port. These sensors, however, only monitor and do not control inlet air temperature.

Thermostatic air inlet and exhaust gas heat riser systems have little impact on fuel economy. Their primary contribution lies in the maintenance of low HC emissions during engine warmup and improvement of cold engine driveability.

3.3 Fuel Systems

Tables 1 and 2 indicate that the fuel systems used in the engines evaluated in this report are either carburetor-based or of the manifold fuel injection type. Domestic engines use carburetor-based systems, while several of the foreign manufacturers use fuel injection. The fuel system, in either case, serves the function of preparing the air/fuel charge for combustion in the engine cylinders. To accomplish this, the air/fuel ratio must be precisely controlled over a wide range of engine speeds and loads to maintain acceptable performance and low exhaust emissions.

The importance of the air/fuel mixture preparation process on exhaust emissions is shown in Figure 1, which presents emissions versus

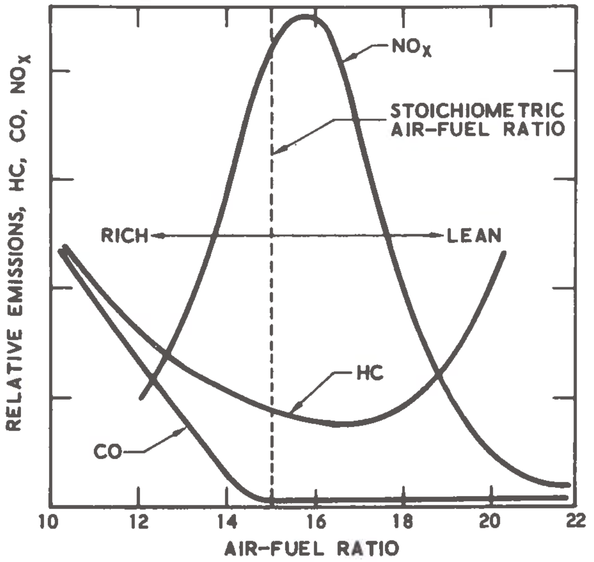


FIGURE 1. EFFECT OF AIR/FUEL RATIO ON EMISSION LEVELS; SPARK-IGNITION ENGINE

air/fuel ratio for spark ignition engines. As indicated, the three emission species NO_x, HC, and CO are highly dependent on the air/fuel ratio. Adjustment to a fuel-rich mixture results in low NO_x emissions, accompanied by an increase in HC and CO as well as fuel consumption, while lean mixture operation substantially reduces these pollutants and improves fuel economy. However, in gasoline engines, air/fuel ratios leaner than approximately 18 result in operational difficulties unless specialized techniques such as charge stratification are used.

3.3.1 Carburetor Fuel Systems

3.3.1.1 Mixture Preparation

In spark ignition engines the function of the carburetor is to provide the proper air/fuel mixture ratio, mix the air and fuel as intimately as possible, and provide a means for regulating engine power. These functions must be accomplished over a wide range of engine speeds and vehicle operating modes such as warmup, idle, acceleration, deceleration, cruise, and wide open throttle (WOT). Figure 2 presents a simplified steady-state air/fuel ratio versus air flow distribution showing the idle and low-load regime (AB), the economy or cruise regime (BC), and the full-load WOT regime (DE).

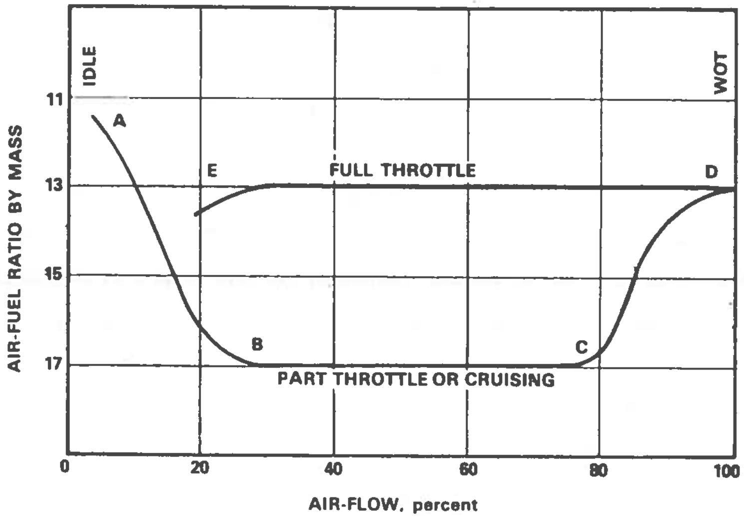


FIGURE 2. AIR/FUEL RATIO REQUIRED BY A SPARK-IGNITION ENGINE AT VARIOUS AIR FLOW RATES

In addition to steady-state operating modes, the carburetor must supply the proper mixtures during transient conditions of cold start, warmup, and acceleration. For compensation of fuel condensation effects in the intake manifold during engine cold start, carburetors have always been adjusted to initially provide a rich air/fuel mixture by means of a choke. While mixture enrichment is also required during engine warmup, the degree of richness is progressively reduced in modern carburetors as fuel vaporization improves with increasing engine temperature.

Unless some supplementary fuel is added to the mixture during acceleration, a momentary lean condition results, arising from both the inertia of the liquid fuel in the manifold and the decrease in vaporization of the fuel at higher manifold pressures. An acceleration pump is generally used to provide the additional fuel.

3.3.1.2 Carburetor Systems, Subsystems, and Devices

For transient operating conditions and exhaust emission control requirements, modern carburetors use various subsystems and devices to supplement the basic idle and main metering circuits.

The cold start or choke control subsystem of a carburetor is of primary importance in limiting HC and CO emissions and in providing fuel enrichment during engine cold start. Since an overly rich charge leads to high HC and CO emissions, sophisticated choke configurations are used in current carburetors to limit choke duration to the minimum required for good driveability. These configurations are based on a bimetallic spring arrangement, actuated electrically or by engine heat, and a vacuum-actuated temperature-modulated fast idle control system.

Since the imposition of exhaust emission regulations, a number of emission-related devices have been added to the carburetor. These devices, which are intended to assist in the control of HC and CO emissions during transient engine conditions, include a solenoid-actuated throttle closer, a temperature-controlled hot idle compensator, a bellows-type altitude compensator, and an idle limiter cap.

Although the lean engine operation is beneficial from a fuel economy point of view, the operational characteristics of the engine and emission control system require lower air/fuel ratios to meet current emission standards while maintaining acceptable vehicle performance and driveability. For example, the air/fuel ratios of spark ignition engines at idle and WOT are determined primarily by driveability and maximum power considerations and, therefore, have remained essentially unaffected by emission control constraints. Conversely, in the off-idle and part-load regimes, substantial air/fuel ratio variations have been implemented as a result of changing emission control standards and techniques. Typically, with the advent of HC and CO controls in 1966 in California (1968 nationwide), the part-load air/fuel ratios have been gradually increased to slightly above stoichiometric from the richer levels used in pre-emission control years. In addition, both idle air/fuel ratio and idle speed have been increased in recent model years to reduce HC and CO emissions at idle, at the expense of a small loss in fuel economy.

In recent model years, different emission control approaches have been adopted by different manufacturers. This has resulted in additional leaning in some engines, while others have been enriched. As an example, the carburetor calibration air/fuel ratio in the Chrysler 318-CID 49-states engine at part throttle has been increased from about 16.7 in 1970 to about 17.8 in 1976. Conversely, the part-load calibration air/fuel ratios used in the Ford 250-CID 49-states engine have been gradually reduced from 15.6 in 1974 to 13.8 in 1976. In recent model years, the carburetion calibration tolerances have been reduced by most manufacturers as a means of providing additional HC and CO control. In general, slightly richer carburetor settings are used in California vehicles.

While calibration data are useful for establishing trends, it should be realized that air/fuel ratios provided by the carburetor in engine installations can vary from these levels because of the transient nature of spark ignition engine operation. Detailed air/fuel ratio schedules for the engines considered in this study are presented in the main body of this report.

3.3.2 Fuel Injection

Two types of fuel injection systems, i.e., continuous or timed pulse, are used in several imported engines evaluated in this study. Both types are manufactured by Bosch of Germany and are designed to provide more precise control of the air/fuel ratio in the interest of assisting in the control of HC and CO exhaust emissions.

The Bosch L-Jetronic timed injection system meters fuel according to sensed engine speed and the inlet air flow rate. These variables are provided to an electronic control module which calculates the proper amount of fuel to be injected into each cylinder. Additional fuel and air for cold start enrichment and fast idle are furnished by a single cold start injector and an auxiliary air passage. Both of these devices are modulated by engine temperature in a manner that reduces their effect with increasing temperature. Currently, the L-Jetronic system is used in the Volkswagen (VW) 96.6-CID Beetle engine.

The Bosch K-Jetronic fuel injection system is an all mechanical system which modulates fuel flow on a continuous basis by modulating the size of a fuel control orifice in accordance with engine air flow. This system is currently used in the Audi 97-CID, Audi 114-CID, Saab 121-CID, VW 97-CID, and Volvo 121-CID engines. Audi calibration data indicate part-throttle air/fuel ratios in the 15.3 to 15.9 range for 1975 and 1976 model year engines.

In general, the use of fuel-injected engines requires less extensive emission control systems than carburetor-equipped engines, as exemplified by the Saab 121-CID engine which currently does not use a catalyst. In a sense, the fuel injection system by itself is an emission control device, at least to the extent that it provides improved cylinder-to-cylinder mixture distribution relative to most current carburetors.

3.4 Ignition System

The function of the ignition system is to provide timed ignition of the air/fuel mixture in each engine cylinder. In the past, this has been accomplished by conventional breaker point ignition systems. These systems have proved inexpensive and simple to maintain and, until recently, have been generally regarded as entirely adequate for automobile applications. However, as exhaust emission control standards have become increasingly stringent, the need for an improved ignition system has become more apparent to eliminate ignition problems caused by breaker-point deterioration and spark plug fouling. This has led to the development and application of advanced ignition systems by a number of manufacturers.

Advanced ignition systems are of two general types: inductive and capacitive discharge (CD) systems. In the inductive breakerless system, a magnetically actuated solid-state switch attached to the distributor shaft triggers the spark. This is similar to a conventional system, as it produces a high voltage in the secondary circuit of the coil by interrupting the current in the primary circuit. Currently, breakerless inductive systems are used by all domestic automobile manufacturers and by a number of foreign manufacturers, including British Leyland, Nissan, and Volvo.

The CD system features a capacitor which permits a rapid discharge of energy in the primary circuit, resulting in a high secondary output voltage to the spark plugs. This provides improved engine starting characteristics, higher voltage in the high-speed regime, and increased spark plug life. Currently, the Audi 100 automobile certified for sale in California is the only vehicle examined in this study which uses a CD ignition system.

Aside from the advanced systems, transistorized versions of conventional breaker-point systems are currently used by some foreign manufacturers, including Toyota and Mercedes Benz. In these systems, breaker-point wear is minimized by using the points as a low voltage/low current switch to trigger a solid-state device in the high-current primary circuit.

3.4.1 Ignition Timing and Spark Advance Modifications

Both HC and NO_x exhaust emissions of spark ignition engines are strongly affected by ignition timing. In general, these pollutants decrease substantially with retarded timing. In the case of NO_x reduction, the mechanism is one of lowering peak cycle flame temperature during combustion. Since the formation of NO_x is exponentially dependent on peak cycle temperature, substantially lower NO_x levels can be achieved by this method. The reduction of HC by means of ignition timing retard is caused by the associated higher exhaust gas temperature, which enhances the oxidation of unburned HC species in the exhaust system.

Although ignition timing retardation reduces exhaust emissions, it has a highly negative impact on fuel economy. Particularly harmful is the reduction or deletion of vacuum advance in the part-throttle cruise condition. For maximum fuel economy, considerable ignition advance is required to allow sufficient time for propagation of the slow burning flame front associated with the lean air/fuel ratios generally used during cruise. However, some retard from the optimum spark advance settings is normally required to meet prevailing emission regulations.

Spark timing control is implemented by adjustment of basic timing, centrifugal advance, vacuum advance, and vacuum retard. In the early years of emission control, almost all manufacturers relied on simple variations in basic timing, centrifugal advance, and vacuum advance for HC and CO control. More recently, vacuum retard features have been implemented to provide additional HC control under certain operating conditions, such as idle, during closed-throttle deceleration, in the lower gears, and within certain engine coolant temperature limits. In addition, the distributor centrifugal and vacuum advance calibration tolerances have been reduced in most vehicles to provide more accurate spark timing for improved emission control. Currently, one or more of these techniques are used by Audi, BMW, Fiat, Nissan, Saab, VW, and Volvo.

Since the advent of NO_x emission control standards, transmission-controlled spark (TCS) has been used by a number of manufacturers, including AMC, General Motors (GM), and Toyota, as a means of selectively eliminating vacuum advance during certain modes of engine operation. TCS was widely used by domestic manufacturers before 1973; however, EGR has succeeded it as the primary NO_x control method. The complete elimination of vacuum advance as an emission control technique has found limited use because of the associated reduction in vehicle fuel economy and durability of certain engine components. Currently, Peugeot is the only manufacturer using this technique.

For additional NO_x control during vehicle acceleration, several manufacturers, including Fiat, GM, and Nissan, use a spark delay unit which delays vacuum advance as the throttle is opened.

3.5 Exhaust Gas Recirculation

Although NO_x emissions can be effectively controlled by intake-exhaust valve overlap, unwanted effects such as rough engine idling and reduced low-speed torque are incurred. To a large extent, these disadvantages can be eliminated by means of EGR. Currently, this technique is used in most automobiles marketed in the United States. Of the 28 engines considered in this study, those not using EGR in 1974 through 1976 are the Fiat 97-CID, the Peugeot 120-CID, and the Toyota 97-CID engines. Other manufacturers not using EGR in some 49-states vehicles include Audi, BMW, and Saab.

With the advent of NO_x emission regulations in 1971 in California, simple EGR systems were introduced in some engines. To eliminate vehicle driveability problems associated with these systems, improved configurations providing better EGR flow modulation followed in subsequent model years.

Ideally, an optimal EGR system meters exhaust gas in direct proportion to engine load with, perhaps, an EGR defeat mechanism at WOT to retain full performance for passing maneuvers. This requires the use of a system control parameter which is readily available and proportional to engine load.

Five types of EGR are currently used by the auto makers: (a) ported vacuum-modulated EGR, (b) intake manifold vacuum-modulated EGR, (c) venturi vacuum-modulated EGR, (d) exhaust backpressure-modulated EGR, and (e) throttle position-modulated EGR. These systems are briefly described in the following paragraphs.

Ported vacuum-modulated EGR systems are controlled by a vacuum signal obtained from a port located in the carburetor slightly above the closed position of the throttle. At idle, no vacuum is transmitted to the EGR valve; consequently, there is no EGR. As the throttle opens, partial vacuum is created at the EGR vacuum port, the EGR valve opens, and exhaust gas is recirculated. Further opening of the throttle leads to lower port vacuum levels until, at WOT, vacuum is too low to hold the EGR valve open, and recirculation ceases. While this system provides EGR modulation which is only roughly proportional to engine load in the low-load regime, it is reasonably effective and the feature of automatic EGR shutoff at WOT is incorporated.

In general, ported EGR is used to a greater degree in 49-states vehicles than in California vehicles, reflecting the less stringent 49-states NO_x standard. To some extent, ported EGR is favored for smaller engines and vehicles, while more complex EGR systems are generally used on larger engine/vehicle configurations. This is exemplified by AMC, which currently uses ported EGR on 49-states 6-cylinder engines and the more sophisticated exhaust backpressure controlled EGR on 49-states V-8 engines. Ford and GM use ported EGR systems more widely than other domestic manufacturers, while BMW, British Leyland, Nissan, Toyota, Saab, and VW are foreign manufacturers using ported EGR in some vehicles.

Intake manifold vacuum-modulated EGR is currently used in GM full size sedans and station wagons certified for California. This system features a dual diaphragm EGR valve which is designed to maintain proportionality between EGR flow rate and engine load over a wide range of engine operating conditions.

Venturi vacuum-modulated EGR uses a weak venturi vacuum signal obtained from the carburetor or from the inlet system of fuel-injected engines. Amplification of the weak signal is provided by a vacuum amplifier using an accumulator charged by manifold vacuum, and the amplified signal is used to control the EGR valve as in the ported system. For EGR defeat at WOT, a relief valve is provided to dump the output EGR signal of the amplifier when venturi vacuum is equal to or greater than intake manifold vacuum. Relative to the ported vacuum system, the venturi vacuum system has the potential of providing EGR flow rates proportional to engine flow over a wide range of engine operating conditions. Among domestic manufacturers both Ford and Chrysler use this type of system, while foreign manufacturers using this system include Audi, Mercedes Benz, Saab, and Volvo.

The most sophisticated approach to meter exhaust gas in proportion to engine load is currently provided by exhaust backpressure-modulated EGR systems. These systems feature a backpressure sensor which protrudes into the exhaust stream and controls a backpressure valve which is in series between the EGR valve and its source of actuating vacuum. Exhaust backpressure modulates the backpressure valve, which in turn modulates the actuating vacuum to the EGR valve. As exhaust gas backpressure is a good measure of engine load, the system more closely approaches the desired EGR versus engine load characteristic than systems based on ported or venturi vacuum. Of the 28 engines considered in this study, the 1975 and 1976 AMC California engines, the 1976 AMC 304-CID 49-state engine, and the Ford 2.8-liter California engine incorporate backpressure EGR systems.

Throttle position-modulated EGR is used in the VW 1976 carbureted single-venturi 97-CID engine. In this system, the EGR valve is actuated by a mechanical linkage arrangement which meters exhaust gas roughly in proportion to engine load.

In addition to the vacuum, backpressure, and throttle position modulation techniques noted above, most EGR systems incorporate engine coolant modulation, which eliminates EGR for improved vehicle driveability during engine warmup when NO_x formation rates are low. Speed modulation is used in the Toyota 133-CID engine to deactivate EGR for vehicle speeds outside of a predetermined range.

Recent studies have shown EGR capable of large reduction in NO_x emissions with little or no decrease in fuel economy. However, to achieve this effect, ignition timing must be set in a manner which causes relatively high HC emissions. This usually results in an emissions control approach which is based on EGR with the ignition timing retarded relative to the optimum fuel economy timing profile. The retarded timing provides the required HC emission reduction, but at the expense of fuel economy.

While EGR is used primarily to control NO_x emissions, it has also proved to be an effective engine knock suppressant, especially for engines operating with rich air/fuel mixtures. This allows some increase in the engine compression ratio which provides a partial recovery of fuel economy losses caused by exhaust emission control systems.

In general, higher EGR flows are used in California vehicles than in 49-states vehicles, reflecting the more stringent California NO_x emission standards. While the NO_x standards have remained essentially constant between 1974 and 1976, higher EGR flow rates generally have been used in 1974 to compensate for EGR system deterioration because of deposit buildup resulting from the widespread use of leaded gasoline.

3.6 Secondary Air Injection

Secondary air, for the suppression of HC and CO emissions, has been widely used by many auto manufacturers since 1966. The air is obtained from an engine-driven air pump and injected into the engine exhaust ports, where it aids oxidation of the HC left unburned in the normal engine combustion process. Currently, secondary air is often used in conjunction with after-treatment devices, such as catalytic converters and thermal reactors, which require the presence of oxygen to promote the oxidation of HC and CO. In secondary air systems, air flow modulation is solely on the basis of engine speed, and demand variations caused by engine load changes are ignored.

As shown in Tables 1 and 2, the use of secondary air systems has increased with the advent of catalysts in 1975. In 1976, a secondary air system is used in all California vehicles except in the Audi 97- and 114-CID engines and in the VW 96-CID engine. Secondary air is used less frequently in the 1976 49-states vehicles.

Fuel economy and power loss penalties associated with the operation of air injection systems are negligible.

3.7 Catalytic Converters

A catalytic converter is an exhaust after-treatment device which contains a catalyst capable of promoting chemical reactions. Catalysts which promote the oxidation of HC and CO into CO_2 and H_2O are referred to as oxidation catalysts. Great efforts have gone into the development of both pelletized and monolithic catalysts for automotive applications, and literally hundreds of different active metal formulations have been tested, including base metal, precious metal, and combined base metal/precious metal combinations. Oxidation catalysts require excess O_2 for HC and CO conversion, which is accomplished by operating the engine sufficiently lean or by adding secondary air in the engine exhaust system upstream of the catalyst. To date, the latter approach has been used almost exclusively.

Necessary attributes for catalytic converters for automotive use include sufficient chemical activity, long life, and resistance to mechanical shock and high temperature. In the early phases of catalyst development, these factors constituted major problem areas which, however, have largely been eliminated in recent catalyst designs.

Precious metal formulations with the total active metal loading varying between approximately 0.04 and 0.11 troy ounces per vehicle are currently used by the auto industry. Typical catalyst compositions contain 70 percent platinum and 30 percent palladium or approximately 90 percent platinum and 10 percent other precious metal elements. The catalysts used by GM and AMC are of the pellet type, whereas all other manufacturers use monolithic substrates. The substrate volume of current catalyst designs varies between about 150 and 250 cu in.

Except for the BMW, Peugeot, and Saab engines, all 1975 and 1976 California engines considered in this study are equipped with a catalytic exhaust control system. As shown in Table 1, catalysts are less widely used in 49-states vehicles. Their use is generally limited to the larger displacement domestic engines.

Catalysts have an indirect but favorable impact on fuel economy because they allow a shift in the HC and CO emission control burden from the engine to an after-treatment device. This allows greater freedom for ignition and fuel supply system optimization, with attendant gains in fuel economy.

The non-availability of durable reduction catalysts has precluded their application for NO_x control in 1976 and earlier model years. However, recent developments by Volvo and Engelhard Industries indicate that catalyst technology has progressed to the point where application in production vehicles appears to be feasible.

3.8 Thermal Reactors

A thermal reactor is an exhaust gas after-treatment device which replaces the conventional engine exhaust manifold. The device is basically a chamber, sized and configured to increase the residence time of engine exhaust gases in the reactor. The increased residence time promotes chemical reactions which reduce HC and CO concentrations in the exhaust.

Thermal reactors may be categorized either as a rich thermal reactor (RTR) or a lean thermal reactor (LTR). The RTR is designed for fuel-rich engine operation. As the exhaust from the cylinders contains large quantities of HC and CO, secondary air supplied by a pump is injected into the exhaust ports upstream of the reactor to permit further oxidation of these species.

In RTR-equipped engines, the chemically reducing atmosphere and lower combustion temperatures form less NO_x than in engines operating with higher air/fuel ratios. NO_x emission levels as low as 0.5 grams/mile have been achieved in experimental RTR configurations. However, this improvement is accompanied by fuel economy penalties of up to 20 percent. Currently, RTR application is limited to the Peugeot 120-CID engine and the California version of the BMW 121-CID engine.

The use of a secondary air system is not required in LTR-equipped engines as they operate with lean mixtures. In this case, the raw HC and CO emissions are much lower than for the RTR, while NO_x is generally somewhat higher. However, since little chemical heat is generated in the LTR, its operating temperature is governed primarily by the sensible heat of the exhaust gas. As a result, the HC and CO oxidation efficiency of the LTR is lower than for the RTR. Currently, LTR systems are not used in production engines primarily because of the associated requirement of more sophisticated carburetors and the difficulty of meeting the current CO standard.

3.9 Crankcase and Evaporative Emission Control Systems

Essentially complete control of crankcase emissions has been effected with closed-loop systems which have replaced open-loop and draft-tube systems used prior to 1968. Evaporative emission control systems, which use a charcoal canister to temporarily store fuel vapors emanating from the fuel tank and carburetor bowl after engine shutdown, provide effective control of evaporated fuel. Evaporative control systems were introduced in 1970 in California and in 1971 nationwide.

Only minor differences in design of crankcase and evaporative emission control systems exist among the various auto manufacturers, and in well maintained engines these systems have little effect on fuel economy or driveability.

4. FUEL ECONOMY AND EMISSIONS

The foregoing sections have pointed out the dependency of automobile fuel economy and emissions on many engine control systems, devices, and techniques. As a summary of these relationships, Tables 3 and 4 present a qualitative compilation of year-to-year modifications in key control systems and parameters and the associated effects on fuel economy and emissions for the 28 engines in the four horsepower classes considered in this study (35-50 HP, 51-75 HP, 76-100 HP, and 101-150 HP). Table 3 characterizes 49-states engine/vehicle configurations, while Table 4 presents California automobiles. In each case, information pertaining to domestic engines is based on automatic transmission vehicles as this configuration is favored by domestic manufacturers. Except for Mercedes Benz, the data for the imported engines represent manual transmission configurations, which are preferred in imported vehicles. In those cases where catalytic and non-catalytic emission control systems are offered in a particular engine/vehicle category, only those with catalysts are considered in Tables 3 and 4.

For better correlation between control system modifications and fuel economy, the EPA certification data used in this study have been normalized for each engine/vehicle class to account for axle ratio and inertia weight variations. Because of the lack of a similar correlation for emissions,

TABLE 3. YEAR-TO-YEAR CHANGES IN ENGINE CONTROLS, FUEL ECONOMY, AND EMISSIONS: 49-STATES APPLICATIONS

Changes In Engine Controls, Fuel Economy, And Emissions: 1976 Relative To 1975												
HP Class	Manufacturer	CID	Spark Timing	Air/Fuel Ratio	EGR Flow	Cat.[a] Or TR[b]	Secondary Air	Valve Overlap	City Fuel Economy, %	HC, %	CO, %	NO_X, %
1	VW[c]	96	Unchanged	NA	Unchanged	Unchanged	Unchanged	Unchanged	~0	~0	~0	+17
2	British Leyland	91	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	+13	~0	-41	-32
	Nissan	85	Retarded	Leaner	Unchanged	Unchanged	Unchanged	Unchanged	+5	~0	+36	-17
	Toyota	97	Unchanged	Richer	Not used	Unchanged	Unchanged	Unchanged	+8	-17	+10	-11
	Fiat	79	Unchanged	Leaner	Not used	Unchanged	Unchanged	Unchanged	~0	+42	-11	+13
	VW[e]	97	Advanced	Richer	Not used 1975	Added Cat.	Unchanged	Unchanged	+6	-84	-18	-40
3	AMC	232	Unchanged	Unchanged	Increased	Unchanged	Unchanged	Unchanged	~0	+25	+38	~0
		258	Unchanged	Unchanged	Increased	Unchanged	Unchanged	Increased[d]	~0	+10	+96	+15
	Chrysler	225	Advanced	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	+8	~0	+16	~0
	Ford	140	Advanced	Richer	Increased	Added Cat.[d]	Unchanged	Unchanged	+15	-19	-20	~0
		171	Advanced	Richer	Increased	Unchanged	Unchanged	Unchanged	+12	+47	+26	~0
		250	Advanced	Richer	Unchanged	Unchanged	Unchanged	Unchanged	+12	+105	-13	-18
	GM	140	Unchanged	Leaner	Unchanged	Unchanged	Unchanged	Increased	-5	+23	+21	+15
	Audi	97	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	+14	~0	~0	+69
		114	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	+5	~0	+17	+13
	BMW	121	Unchanged	Leaner	Unchanged	Deleted TR	Unchanged	Unchanged	~0	+166	+233	+100
	British Leyland	110	NA	NA	NA	Added Cat.	Unchanged	Unchanged	-19	NA	NA	NA
	Nissan	119	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	+7	+20	+38	~0
	Peugeot	120	Unchanged	Unchanged	Not used	Unchanged	Unchanged	Unchanged	-12	-44	-13	~0
	Toyota	134	Retarded	Unchanged	Reduced	Unchanged	Unchanged	Unchanged	+11	+37	+37	~0
	Volvo	121		Replaced with new design in 1976								
4	AMC	304	Retarded	Richer	Increased	Unchanged	Unchanged	Unchanged	-7	+17	+47	-12
	Chrysler	318	Retarded	Unchanged	Increased	Unchanged	Unchanged	Unchanged	+11	+46	+43	+11
	Ford	351	Advanced	Richer	Increased	Unchanged	Unchanged	Unchanged	+19	-42	-32	~0
	GM	250	Unchanged	Leaner	Reduced	Unchanged	Unchanged	Unchanged	+9	+30[g]	+60[g]	~0[g]
		350(2V)	Unchanged	Leaner	Unchanged	Unchanged	Unchanged	Unchanged	~0	~0	+12	~0
	Mercedes Benz	168	Unchanged	Leaner	Reduced	Unchanged	Unchanged	Unchanged	-7	-16	-38	~0
	Saab	121	Unchanged	NA	Not used	Unchanged	Unchanged	Unchanged	-5	NA	NA	NA

[a] Cat. = Catalyst, [b] TR = Thermal reactor, [c] VW Beetle, [d] Not all models, [e] VW Rabbit and Scirocco [f] Engine family with AIR [g] Non-EFE vehicles

TABLE 3. CONTINUED

Changes In Engine Controls, Fuel Economy, And Emissions: 1975 Relative To 1974

HP Class	Manufacturer	CID	Spark Timing	Air/Fuel Ratio	EGR Flow	Cat.[a] Or TR[b]	Secondary Air	Valve Overlap	City Fuel Economy, %	HC, %	CO, %	NO_x, %
1	VW[c]	96	Unchanged	NA	Increased	Unchanged	Unchanged	Increased	~0	-39	-61	-28
2	British Leyland	91	Retarded	NA	NA	Unchanged	Added AIR	Unchanged	-7	-56	-57	-52
	Nissan	85	-	-	-	-	-	-	-	-	-	-
	Toyota	97	Advanced	Richer	Not used	Unchanged	Added AIR	Increased	-7	-36	-44	-90
	Fiat	79	Unchanged	Unchanged	Not used	Added Cat.[d]	Unchanged	Unchanged	+8	NA	NA	NA
	VW[e]	97	-	-	-	-	-	-	-	-	-	-
3	AMC	232	Advanced	Richer	Reduced[d]	Unchanged	Unchanged	Reduced	+15	-40	-44	-11
		258	Advanced	Richer	Increased	Unchanged	Unchanged	Reduced	+17	-43	-68	-11
	Chrysler	225	Unchanged	Leaner	Unchanged	Added Cat.	Unchanged	Unchanged	~0	-63	-68	-16
	Ford	140	Unchanged	Unchanged	Reduced	Unchanged	Unchanged	Unchanged	~0	-23	-53	-51
		171	Unchanged	Unchanged	Unchanged	Added Cat.	Unchanged	Unchanged	-8	-70	-69	~0
		250	Retarded	Richer	Increased	Added Cat.	Added AIR	Reduced	-7	-82	-87	~0
	GM	140	Advanced	Unchanged	Reduced	Added Cat.[f]	Unchanged[f]	Unchanged	~0	-56	-42	-11
	Audi	97	-	-	-	-	-	-	-	-	-	-
		114	Unchanged	Richer	Unchanged	Unchanged	Deleted AIR[d]	Unchanged	+20	NA	NA	NA
	BMW	121	NA	Unchanged	Unchanged	Added TR[b]	Added AIR	Unchanged	-21	NA	NA	NA
	British Leyland	110	NA	NA	Increased	Unchanged	Unchanged	Reduced	~0	NA	NA	NA
	Nissan	119	Advanced	Richer	NA	Unchanged	Unchanged	Unchanged	~0	-52	-44	+60
	Peugeot	120	Unchanged	Unchanged	Not used	Added TR[b]	Unchanged	Increased	+15	-20	-19	~0
	Toyota	134	-	-	-	-	-	-	-	-	-	-
	Volvo	121	Retarded	NA	Unchanged	Unchanged	Added AIR	Reduced	-15	NA	NA	NA
4	AMC	304	Advanced	Unchanged	Reduced	Added Cat.	Added AIR	Unchanged	+9	-84	-69	~0
	Chrysler	318	Advanced	Leaner	Unchanged	Added Cat.	Unchanged	Unchanged	+8	-70	-47	-34
	Ford	351	Retarded	Richer	Reduced	Added Cat.[d]	Added AIR	Increased	~0	-51	-53	-11
	GM	250	Unchanged	Leaner	Reduced	Added Cat.	Deleted AIR[d]	Unchanged	~0	NA	NA	NA
		350(2V)	Advanced	Leaner	Reduced	Added Cat.	Deleted AIR	Unchanged	+10	-79	-64	~0
	Mercedes Benz	168	Advanced	Leaner	NA	Added Cat.	Added AIR	Reduced	NA	-88	-75	-28
	Saab	121	Advanced	NA	Not used	Unchanged	Unchanged	Increased	+16	-46	-57	+23

[a] Cat. = Catalyst, [b] TR = Thermal reactor, [c] VW Beetle, [d] Not all models, [e] VW Rabbit and Scirocco, [f] Engine family with AIR not considered, [g] Non-EFE vehicles

TABLE 4. YEAR-TO-YEAR CHANGES IN ENGINE CONTROLS, FUEL ECONOMY, AND EMISSIONS: CALIFORNIA APPLICATIONS

Changes In Engine Controls, Fuel Economy, And Emissions: 1976 Relative To 1975

HP Class	Manufacturer	CID	Spark Timing	Air/Fuel Ratio	EGR Flow	Cat.[a] Or TR[b]	Secondary Air	Valve Overlap	City Fuel Economy, %	HC, %	CO, %	NO_x, %
1	VW[c]	96	Unchanged	NA	Unchanged	Unchanged	Unchanged	Unchanged	+11	+22	-23	+87
2	British Leyland	91	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	~0	~0	~0	~0
	Nissan	85	Retarded	Leaner	Unchanged	Unchanged	Unchanged	Unchanged	+5	+38	+33	~0
	Toyota	97	Unchanged	Unchanged	Not used	Unchanged	Unchanged	Unchanged	~0	-11	~0	~0
	Fiat	79	Unchanged	Leaner	Not used	Unchanged	Unchanged	Unchanged	~0	NA	NA	NA
	VW[d]	97	Unchanged	Richer	Unchanged	Unchanged	Unchanged	Unchanged	+6	+50	+380	-36
3	AMC	232	Retarded	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	-7	+20	~0	~0
		258	Advanced	Unchanged	Unchanged	Unchanged	Unchanged	Increased[e]	~0	+50	~0	~0
	Chrysler	225	Unchanged	Unchanged	Reduced	Unchanged	Unchanged	Unchanged	~0	~0	~0	-30
	Ford	140	Advanced	Richer	Unchanged	Unchanged	Unchanged	Unchanged	+11	+113	+46	~0
		171	Unchanged	Unchanged	Reduced	Unchanged	Unchanged	Unchanged	+14	+33	+53	-24
		250	Advanced	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	+5	+70	+28	~0
	GM	140	Unchanged	Leaner	Unchanged	Unchanged	Unchanged	Increased	~0	-53	-29	-26
	Audi	97	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	+9	~0	+17	+33
		114	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	~0	~0	-10	+41
	BMW	121	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	+10	+33	+66	+40
	British Leyland	110	Retarded	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	~0	~0	~0	~0
	Nissan	119	Unchanged	Richer	Reduced	Unchanged	Unchanged	Unchanged	+8	+50	+33	~0
	Peugeot	120	Unchanged	Unchanged	Not used	Unchanged	Unchanged	Unchanged	-9	+20	+27	-23
	Toyota	134	Retarded	Richer	Reduced	Unchanged	Unchanged	Unchanged	+19	~0	+10	-23
	Volvo	121		Replaced with new design in 1976								
4	AMC	304	Retarded	Richer	Unchanged	Unchanged	Unchanged	Unchanged	-12	+24	+39	-16
	Chrysler	318	Retarded	Richer	Mixed	Unchanged	Unchanged	Unchanged	~0	+86	-45	+11
	Ford	351	Advanced	Richer	Increased	Unchanged	Unchanged	Unchanged	+39	-23	-20	~0
	GM	250	Advanced	Leaner	Unchanged	Unchanged	Unchanged	Unchanged	~0	+13	-54	+26
		350(2V)	Retarded	Richer	Unchanged	Unchanged	Unchanged	Unchanged	~0	~0	+13	+15
	Mercedes Benz	168	Unchanged	Leaner	Reduced	Unchanged	Unchanged	Unchanged	-7	-16	-38	~0
	Saab	121	Unchanged	NA	Unchanged	Unchanged	Unchanged	Unchanged	-9	+50	+11	~0

[a] Cat. = Catalyst, [b] TR = Thermal reactor, [c] VW Beetle, [d] VW Rabbit and Scirocco, [e] Not all models

TABLE 4. CONTINUED

Changes In Engine Controls, Fuel Economy, And Emissions: 1975 Relative To 1974

HP Class	Manufacturer	CID	Spark Timing	Air/Fuel Ratio	EGR Flow	Cat.[a] Or TR[b]	Secondary Air	Valve Overlap	City Fuel Economy, %	HC, %	CO, %	NO_x, %
1	VW[c]	96	Unchanged	NA	Increased	Added Cat.	Unchanged	Increased	~0	-77	-60	-65
2	British Leyland	91	Retarded	NA	NA	Added Cat.	Added AIR	Unchanged	~0	-83	-87	~0
	Nissan	85	-	-	-	-	-	-	-	-	-	-
	Toyota	97	Unchanged	Richer	Not used	Added Cat.	Unchanged	Unchanged	~0	-72	-74	~0
	Fiat	79	Unchanged	Unchanged	Not used	Added Cat.	Unchanged	Unchanged	+5	NA	NA	NA
	VW[d]	97	-	-	-	-	-	-	-	-	-	-
3	AMC	232	Unchanged	Richer	Reduced	Added Cat.	Added AIR	Reduced	~0	-89	-73	~0
		258	Unchanged	Richer	Reduced	Added Cat.	Added AIR	Reduced	~0	-90	-74	-29
	Chrysler	225	Unchanged	Richer	Reduced	Added Cat.	Added AIR	Unchanged	NA	NA	NA	NA
	Ford	140	Unchanged	Richer	Unchanged	Added Cat.	Unchanged	Unchanged	~0	-77	-78	-34
		171	Retarded	Leaner	Increased	Added Cat.	Unchanged	Unchanged	-7	-80	-79	~0
		250	Retarded	Richer	Unchanged	Added Cat.	Unchanged	Reduced	~0	-72	-83	~0
	GM	140	Advanced	Richer	Increased	Added Cat.	Added AIR	Unchanged	~0	-69	-46	-12
	Audi	97	-	-	-	-	-	-	-	-	-	-
		114	Unchanged	Richer	Unchanged	Added Cat.	Deleted AIR	Unchanged	+14	NA	NA	NA
	BMW	121	NA	Unchanged	Unchanged	Added TR	Added AIR	Unchanged	-21	NA	NA	NA
	British Leyland	110	Retarded	Leaner	NA	Added Cat.	Unchanged	Reduced	-16	NA	NA	NA
	Nissan	119	Unchanged	Richer	NA	Added Cat.	Unchanged	Unchanged	-5	-83	-85	+22
	Peugeot	120	Unchanged	Unchanged	Not used	Added TR	Unchanged	Increased	+8	-56	-29	+27
	Toyota	134	-	-	-	-	-	-	-	-	-	-
	Volvo	121	Retarded	NA	Increased	Added Cat.	Added AIR	Reduced	-5	NA	NA	NA
4	AMC	304	Advanced	Unchanged	Reduced	Added Cat.	Unchanged	Unchanged	+23	-87	-79	-54
	Chrysler	318	Advanced	Leaner	Reduced	Added Cat.	Added AIR	Unchanged	NA	NA	NA	NA
	Ford	351	-	-	-	-	-	-	NA	NA	NA	NA
	GM	250	NA	NA	NA	Added Cat.	Unchanged	Unchanged	NA	NA	NA	NA
		350(2V)	Advanced	Leaner	Reduced	Added Cat.	Unchanged	Reduced	+14	-77	-80	~0
	Mercedes Benz	168	Advanced	Leaner	NA	Added AIR	Unchanged	Unchanged	+26	-51	-69	-15
	Saab	121	Advanced	NA	Increased	Unchanged	Added AIR	Increased	+11	-76	-65	~0

[a] Cat. = Catalyst, [b] TR = Thermal reactor, [c] VW Beetle, [d] VW Rabbit and Scirocco

the emission data are based directly on the certification data, with an adjustment for the different test procedures used in 1974 and in 1975/1976.

Tables 3 and 4 trace the variations in spark timing, air/fuel ratio, EGR flow, exhaust after-treatment, and valve overlap in a qualitative manner. Over the operating regime of the Federal Driving Cycle, 6 of the 12 domestic 49-states engine/vehicle configurations exhibit an increase in spark advance in 1975 relative to 1974; 2 engines show spark retard; and 4 remain essentially unchanged. Except for the AMC 232- and 258-CID engines, the domestic vehicles showing increased spark advance in 1975 are catalyst-equipped, while five of the six vehicles with retarded or unchanged spark advance in 1975 use a catalyst. With regard to imported vehicles, only four show advanced timing in 1975 as compared to 1974, with the remainder about equally divided between retarded and unchanged timing. Relative to 1975, spark advance has been increased in 1976 in a number of additional domestic vehicles, while the timing of the other domestic vehicles has remained unchanged or was slightly retarded. Conversely, spark timing of the imported vehicles in 1976 remains essentially unchanged from the 1975 levels except for two vehicles which show retarded timing, and one vehicle which shows advanced timing. While somewhat lower spark advance is generally used in California, the spark advance changes implemented in the California vehicles between 1974 and 1976 exhibit trends similar to the 49-states vehicles.

With regard to changes in the air/fuel mixture ratio of the 49-states calibrations, a number of engines have been leaned out in the 1974/1975 and 1975/1976 time periods, while approximately equal numbers were enriched or remained essentially unchanged, with no clear trends apparent between the domestic and imported vehicles. The same general trends are observed for the California vehicles, with a slight bias toward mixture enrichment in both time periods.

With few exceptions, the EGR flow rate has been reduced or held unchanged between 1974 and 1975 in both 49-states and California vehicles. This decline is related to the increased use of unleaded gasoline in 1975, which inhibits EGR system deterioration caused by lead-deposit buildup in the EGR valve. The EGR system configurations and calibrations remain essentially unchanged between 1975 and 1976, with lower EGR rates implemented in some 1976 engines. This trend is not surprising considering that the NO_x standards

(49-states and California) have remained unchanged for these two years. However, relative to 1975, more EGR is used in some 1976 engines to provide a larger margin between NO_x emissions and NO_x standards.

The principal exhaust after-treatment systems incorporated in 1975 and retained in 1976 include oxidation catalysts and secondary air injection. These systems, either alone or in combination, are used primarily in the larger engine/vehicle installations, particularly in California. In the main, valve overlap has remained unchanged between 1974 and 1976 although some engines show a reduction in overlap in 1975 while others show an increase in 1975 and 1976.

The effects of control system modifications and of adjustments in component calibrations on the normalized city fuel economy and on the emissions (Tables 3 and 4) indicate an improvement in fuel economy for many vehicles in 1975 over their 1974 counterparts. This has been accompanied by substantial reductions in HC and CO emissions. In the main, these trends are directly related to the use of catalysts which permit an increase in spark advance, either directly by increasing basic timing, centrifugal advance, and/or vacuum advance or by deleting spark advance defeat devices which have been used in previous years for emission control purposes by some manufacturers. However, while using a catalyst, some manufacturers did not initially take advantage of the potential the catalyst offers for system optimization and, therefore, did not achieve better fuel economy in their vehicles in 1975. Since the exhaust emissions of the 1975 vehicles were generally substantially below the 49-states and California emission standards most manufacturers recalibrated their 1976 engine control systems achieving improved fuel economy, accompanied by some increase in emissions. While the 49-states and California vehicles show similar fuel economy and emission trends, the fuel economy level of the 1974-1976 California vehicles is generally of the order of 10 percent lower than for the equivalent 49-states vehicles, reflecting the more stringent California emission regulations. The domestic vehicles with manual transmission and imported vehicles with automatic transmission exhibit similar fuel economy and emission trends.

The apparent inconsistencies between the control system changes and the associated variations in fuel economy and emissions observed in Tables 3 and 4 for some engines are attributed, at least in part, to uncertainties in the certification data, caused by a number of factors. These include the small data sample for many vehicles, the normal test-to-test and vehicle-to-vehicle variabilities, and the potential inaccuracies in the fuel-economy normalization procedure. Other factors which might contribute to the observed discrepancies include the use of air conditioning (A/C) and radial tires in some vehicles and model years and year-to-year variations in transmission efficiency.

On balance, the fuel economy improvement of the imported automobiles between 1974 and 1976 is less than that of the domestic vehicles. This trend is attributed to the generally smaller size of the imported engine/vehicle configurations, which permits the use of less sophisticated emission control systems in these vehicles. Since the imported cars have historically had a fuel economy advantage over their domestic counterparts, there has been less incentive in the past for the foreign manufacturers to use sophisticated control systems and to apply extensive system optimization procedures.

5. CONCLUDING REMARKS

As can be seen from the results of the survey, the principal automobile engine control techniques involve the fuel system, intake system, ignition system, engine modifications, EGR, and catalytic after-treatment with or without secondary air injection. Each manufacturer has used specific control-system combinations for each particular engine, model year, and emission-calibration level.

On an individual engine basis, tracking the year-to-year changes in control system modifications and techniques provides valuable insight into the relationships between control system settings, fuel economy, and emissions.

On an overall basis, the inherent differences between the various engine designs do not permit other than general observations to be made. Without an oxidation catalyst, vehicle fuel economy is adversely affected by the requirement of spark retard and internal or external EGR to meet the 1975/1976 California and 49-states emission standards. Conversely, the application of an oxidation catalyst has largely removed these constraints, permitting the use of more optimum spark advance schedules. Recent improvements in EGR system design (i.e., backpressure modulated EGR) have reduced the impact of this particular NO_x abatement technique on fuel economy. However, in each case, it is necessary to examine the specific engine/ vehicle configuration to quantize the effects of the various control parameters on fuel economy and emissions.

1. INTRODUCTION

1.1 BACKGROUND

During the past few years, the demand for petroleum fuels has increased at a rapid rate, while petroleum production from domestic sources has been steadily declining. Even the flow of Alaskan oil in 1977 and the potential production from new offshore oil fields coupled with more intensive recovery from existing wells will not be sufficient to solve the imbalance of crude oil supply and demand in the United States. Until other energy sources are developed, more efficient use of the available sources, by increasing the efficiency of automobile engines, can make a significant contribution toward alleviating the existing condition.

Currently, the petroleum consumption of the United States transportation sector accounts for approximately 55 percent of the total petroleum use with the automotive sector (i. e., cars, buses, and trucks) contributing about 75 percent to that amount. The potential for significant fuel saving is thus evident if the fuel economy of the automotive sector can be improved. In quantitative terms, a 1-percent improvement in vehicle fuel economy results in monetary savings of about 500 million dollars annually.

Both the U. S. Department of Transportation (DOT) and the Energy Research and Development Administration (ERDA) are currently engaged in the conduct of programs aimed at evaluating, projecting, and improving the fuel economy characteristics of automotive powerplants, consistent with current and future emission regulations. The DOT Automotive Energy Efficiency Program (AEEP), initiated in 1973, is designed to provide factual data and objective analyses relevant to vehicle fuel consumption. Through in-house and contracted work, this program investigates the effects on fuel economy of engine modifications and component adjustments and additions and assesses the potential for powerplant improvements in terms of fuel economy and emissions. The Advanced Automotive Power Systems (AAPS) Program of ERDA is structured to foster and to augment the technological development of alternative engines (e. g., gas turbine, stratified charge, diesel, Rankine cycle) with particular emphasis on reduced fuel consumption and exhaust emissions. This study is part of the DOT overall AEEP Program.

1.2 STUDY OBJECTIVES AND SCOPE

The objectives of this study are to survey, evaluate, and document the engine control practices used in current and selected earlier model years and to perform sensitivity analyses of engine performance as affected by controllable operating parameters and incorporation of improved control systems and techniques.

Four horsepower classes (35-50 HP, 51-75 HP, 76-100 HP, and 101-150 HP) and seven emission levels (uncontrolled and the 1974, 1975, and 1976 California and 49-states) are considered in this study. Frequently, one additional model year (1970 or 1972) is included to supplement the limited calibration data generally available for uncontrolled engines. In addition, the fuel economy data of the 1973 certification vehicles are considered to assist in the evaluation of the fuel economy trends of the selected engine/vehicle configurations.

The study is limited to conventional spark ignition engines. Advanced engines based on the Brayton, Rankine, and Stirling cycle are not considered because they are currently being evaluated and/or developed as part of the ERDA AAPS program.

1.3 METHOD OF APPROACH

The objectives of the study have been met by means of two analytic tasks. The first task involved the organization and conduct of the Automobile Engine Control Workshop/Symposium on automobile engine controls. This workshop/symposium provided a forum for technical interchange in the automobile engine controls area and permitted a basis of perspective with regard to the potential benefits in fuel economy and emissions resulting from the use of improved control techniques. The papers presented are included as a separate report (see DOT-TSC-OST-76-15, dated April 1976); the highlights of the meeting are presented in Section 1.4.

In the engine technology area, the emphasis was placed on lean engine concepts and the required component modifications, including high-intensity ignition, increased intake air turbulence, improved fuel atomization and vaporization, and improved mixture distribution. While some spark ignition engines were operated successfully at air/fuel ratios beyond 25:1, it would appear that the 18-20 air/fuel ratio range might be more desirable with regard to optimizing both fuel economy and emissions.

Based on the available data, it would seem that lean spark ignition engines have the capability of meeting NO_x standards as low as 1 g/m, but can not reach the 0.4 g/m level.

In the area of engine optimization and constraints, a number of papers stressed the impact of emission regulations on the optimization process of automobile engines. Because of the transient nature of automobile engine operation and the dependence of engine emissions on transient conditions, many individuals feel that dynamic engine optimization is urgently needed.

Several authors presented test data showing the impact of emission standards on the fuel consumption of current engines and discussed the engine technology required to meet these standards. In the absence of a NO_x catalyst, some spark retard would be required to meet NO_x levels below about 2 g/m at the expense of some loss in fuel economy. Uncertainties regarding future NO_x standards appear to inhibit the development of stratified charge engines by the automakers.

Several papers described various sensing and control techniques, including the measurement of exhaust gas species, air mass flow sensors, air flow modulation measurement of cylinder peak pressure, and the application of microprocessors to automotive control systems. The non-availability of suitable sensors inhibits the development and application of advanced engine control systems.

In the second task, the control systems and techniques applied in 28 selected domestic and imported automobile engines are reviewed, with particular emphasis on the impact of the changes in emission regulations on engine control system design and operation. The results of this effort are presented in this report.

1.4 AUTOMOBILE ENGINE CONTROL SYMPOSIUM

The first Automobile Engine Control Workshop/Symposium was conducted at DOT, TSC on July 8-9, 1975. A total of 19 papers were presented at the meeting, and a number of pertinent subject areas were addressed by the speakers, including the following:

a. Engine modeling and control variables
b. Engine technology
c. Optimization and constraints
d. Impact of emission standards
e. Sensing and control techniques

With regard to engine control variables, the interrelationships were examined between various engine control parameters, such as spark advance, turbulence level, mixture homogeneity, air/fuel ratio and chamber shape, and important engine performance factors, such as fuel consumption and emissions. Estimates were presented of potential improvements in fuel economy which might be achieved with improved engine design and control systems, incorporating catalysts or thermal reactors.

2. ENGINE CONTROL APPROACHES AND TECHNIQUES

2.1 INTRODUCTION

Historically, pre-emission control automobile engines have been calibrated for maximum performance consistent with acceptable idle and driveability characteristics. Fuel economy has been of secondary interest to the motorist in the United States, and automobile engines have been generally operated with rich air/fuel mixtures to assure delivery of a combustible mixture to each engine cylinder under all operating conditions in spite of the rather large non-uniformities in the flow distirbution provided by the intake system.

The advent of HC and CO emission control in 1966 in California and in 1968 nationwide has lead to the application of leaner air/fuel mixtures in conjunction with improvements in fuel atomization, fuel vaporization, and intake-flow distribution. While these modifications have been generally beneficial from a fuel-economy point of view, subsequent promulgation of NO_x emission standards and the emerging trend towards unleaded, lower octane gasoline, have resulted in the use of engine-control modifications which have proved to be detrimental to fuel economy. These modifications include increased intake/exhaust-valve overlap, reduction in engine-compression ratio, and the use of spark-retard and EGR. In addition, carburetor enrichment has been implemented in some engines in conjunction with secondary air injection into the exhaust ports for added HC and CO control.

Since the oil embargo in 1973, most automobile manufacturers have made serious efforts toward improving automobile fuel economy through vehicle weight, engine size, and rear axle ratio reductions, combined with the implementation of engine and control system modifications and optimizations.

An overview of the various engine-related techniques and systems used by the automobile industry to meet the changing emission regulations and to improve vehicle fuel economy is presented in Section 2.2. The systems and devices considered encompass design modifications and calibration adjustments of conventional engine components, such as the valves, intake system, fuel supply system, as well as the systems added for emission control reasons only. These include secondary air injection, EGR, thermal reactors, and oxidation catalysts. Particularly, the use of catalytic systems has provided an opportunity for substantial improvements in fuel economy and emissions.

Generally, advanced control techniques, such as lean burn concepts, reduction catalysts, three-way catalysts, and feedback control systems have not yet reached the production stage. However, because of their beneficial effect on fuel economy and emissions, and their potential widespread introduction in the near-to-intermediate term, these concepts are also briefly addressed in this section.

2.2 ENGINE CONTROL SYSTEMS

2.2.1 Engine Modifications

Engine modifications, as defined for the purpose of this report, refer to internal changes made to the basic engine. For example, variations in combustion chamber configuration and intake-exhaust valve timing constitute examples of engine modifications discussed in this section. Modifications to engine components or systems external to the engine block, such as the distributor or fuel delivery system, are considered to be modifications of the individual component/system and are treated in separate sections.

2.2.1.1 Combustion Chamber Configuration and Surface-to-Volume Ratio

The design of the combustion chamber has an important influence on engine performance in terms of fuel economy, driveability, and HC and NO_x emissions. The shape of the combustion chamber and the relative location of the valves affect the flow pattern and the degree of turbulence, and, consequently, the speed of flame propagation and the thickness of the wall boundary layer. Intensive turbulence tends to decrease the thickness of the wall quench layer and promotes the post-flame oxidation of the HC species in the boundary layer. In addition, it increases the combustion pressure rise rate, the peak combustion temperature, the formation of NO_x, and the heat transfer to the cylinder walls. On the other hand, intensive turbulence tends to decrease the selective retention of HC-rich boundary layer gases in the combustion chamber during the exhaust stroke, resulting in an increase in HC emissions.

In general, combustion chambers with a high surface-to-volume ratio tend to produce lower NO_x emissions than compact chambers. This results because the formation of NO_x is exponentially dependent on peak combustion temperature, and high-surface-area chambers offer greater cooling capacity and, therefore, lower combustion temperatures. However, as noted, a large surface area increases the size of the wall boundary layer and contributes to quenching of the combustion gases with an attendant increase in the formation of HC. In contemporary combustion chamber design, this tradeoff between the formation of HC and NO_x is most often resolved in favor of limiting the formation of HC. Control of NO_x is then implemented by using intake charge dilution achieved via modified intake-exhaust valve overlap or by EGR. Both of these techniques are discussed in the following paragraphs.

The influence of several key engine design parameters on surface-to-volume ratio is shown in Figure 2-1. As seen in this figure, lower surface-to-volume ratios tend to be associated with lower compression ratios. However, the lower compression ratios used in most current automobile engines are not primarily the result of a trend toward low surface-to-volume ratio combustion chambers. Rather, compression ratios have generally been lowered to achieve knock-free engine operation with unleaded gasoline, which

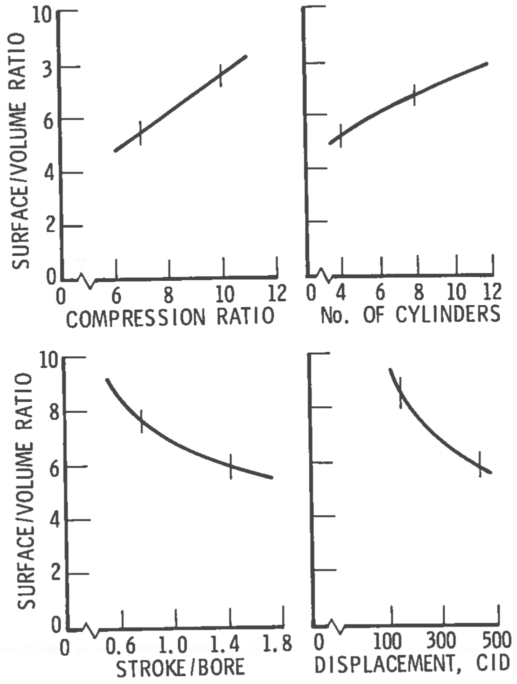


FIGURE 2-1. EFFECT OF COMBUSTION CHAMBER GEOMETRY ON THE SURFACE-TO-VOLUME RATIO (Ref. 2-1)

is required for catalyst-equipped vehicles. In some cases, manufacturers specify the use of unleaded gasoline in non-catalyst engines. This is probably done in the interests of standardization and attendant cost savings to the manufacturer although it imposes a fuel cost penalty as unleaded fuel is slightly more expensive than leaded fuel of equivalent octane rating. However, higher per unit fuel costs may be offset to some extent by lower maintenance costs associated with the cleaner burning unleaded fuel. In any case, lower compression ratios exact their own price in vehicle performance by lowering engine efficiency. Typically, a reduction in compression ratio from 9 to 8 decreases vehicle fuel economy by about 3 to 5 percent. While this reduction is not as large as the fuel economy losses associated with certain engine emission control methods discussed in other sections, it does have a distinct and measurable negative impact.

As expected from geometrical considerations, surface-to-volume ratio increases with decreasing engine displacement and stroke-to-bore ratio and with increasing number of cylinders at constant engine displacement.

2.2.1.2 Valve Timing

Traditionally, the major objective of cam design for the timed actuation of the valve system has been the achievement of high volumetric efficiency over the entire operating range of the engine. However, with the advent of NO_x emission standards, valve timing modifications have been incorporated in some engines to reduce the combustion temperatures and NO_x formation rates by increasing the dilution of the intake charge with residual gases from the cylinders.

The degree of NO_x reduction achieved by means of valve timing modifications is affected by both the amount and temperature of the internally recycled exhaust gas. In the case of early inlet valve opening, a fraction of the combustion gases is discharged into the inlet manifold where the gases are cooled in contact with the relatively cold walls of the inlet manifold. During the intake stroke, the cooled exhaust gases are then returned to the engine cylinder, thus providing charge dilution.

Since early inlet valve opening causes the exhaust system to be in communication with the low-pressure intake system for a longer period of time, exhaust gases are returned to the cylinder through the exhaust valve.

The exhaust gas backflow originates from the end of the exhaust stroke and, thus, is expected to have higher HC concentrations. Retention of these HC-rich quench gases in the engine is believed to be the main reason for the observed reduction in HC emissions. Late intake valve opening generally increases NO_x slightly, but has little effect on HC. In general, intake valve timing has little or no effect on CO (Refs. 2-2 through 2-4).

Some reduction in HC and NO_x has been achieved with early exhaust valve closing, as well as late closing. Apparently, early closing of the exhaust valve prevents the discharge of HC-rich quench gases, and, therefore, is more effective in reducing the emission of HC than late closing. On the other hand, late exhaust valve closing is more effective for NO_x abatement because of higher cooling of the residual gases in the inlet manifold. Exhaust valve-closing timing has no significant effect on CO and specific fuel consumption.

Recent examples of changes in intake valve timing are often associated with the introduction of external EGR. Before the widespread application of EGR, intake charge dilution for purposes of NO_x control is achieved by relatively high levels of intake/exhaust valve overlap. As NO_x reduction is nearly insensitive to the manner in which charge dilution is obtained, the introduction of EGR allows a decrease in valve overlap accompanied by improved engine idle and low-speed torque characteristics. For this reason, valve overlap is no longer used as a primary NO_x control method.

2.2.2 Intake System

The engines evaluated in this study are equipped with either a carburetor or a manifold fuel injection delivery system. While the air intake systems for these two fuel delivery methods provide the same basic function, some important design differences exist. In both fuel delivery methods, the intake system routes filtered air to the point at which air and fuel are mixed before delivery to the cylinders. In the carburetor system, this is typically at a single point well upstream of the cylinders (i.e., at the carburetor), while in manifold injection systems, preparation of the air/fuel mixture occurs in the intake manifold adjacent to each cylinder intake valve. The dissimilar distance which the air/fuel mixture travels in the two systems imposes different requirements on the intake system and gives rise to the design variations discussed below.

A design objective of late model carburetor-based intake systems is the enhancement of fuel vaporization to assist in providing uniform cylinder-to-cylinder air/fuel mixture distribution. While this is particularly important to reduce the emission of HC during engine warmup in carbureted systems, it is less important in fuel-injected systems as the distance the air/fuel mixture travels to the cylinders is very short.

To improve the fuel vaporization and emission characteristics, most modern carburetor-based fuel systems rely on preheated or thermostatically controlled air intake systems. In these configurations, the exhaust manifold is used as a source of warm air which is mixed with ambient underhood air in proportions controlled by a flap valve situated in the snorkel of the air cleaner. A temperature sensor, usually located in a protected position on the clean side of the air cleaner, is used to monitor inlet air temperature, and to provide a control input signal to a vacuum motor which positions the flap valve, thereby maintaining a near-constant inlet air temperature of approximately 100°F.

In addition to thermostatic control of intake air, many domestic and foreign automobile manufacturers currently use thermostatically controlled exhaust gas heat-riser systems on carburetor-equipped engines. During engine warmup, these systems route hot exhaust gases through passages in the intake manifold, thereby transferring exhaust gas heat to the intake charge.

Generally, exhaust gas heat-riser or thermostatically controlled air inlet systems are not used on fuel injected engines. However, time-modulated fuel injection systems often rely on an air temperature sensor in the intake system to provide an input to the fuel injection control module which uses air temperature as one of the variables to calculate the amount of fuel to be injected into each cylinder intake port. These sensors, however, only monitor and do not control inlet air temperature.

Thermostatic air inlet and exhaust gas heat-riser systems have little inpact on fuel economy. Their primary contribution is in the maintenance of low HC emissions during engine warmup and in the improvement of cold engine driveability.

2.2.3 Fuel Systems

The fuel systems used in current automobile engines are either carburetor-based or of the manifold fuel injection type. With few exceptions, carbureted systems are used by all domestic manufacturers, while several foreign manufacturers use fuel injection. In either case, the fuel system serves the primary function of preparing the air/fuel charge for efficient combustion in the engine cylinders. This requires precise air/fuel ratio control over a wide range of engine speeds and loads, with the control of exhaust emissions as a primary consideration.

To illustrate the importance of the air/fuel mixture preparation process on exhaust emissions, Figure 2-2 presents a graph of exhaust emissions versus air/fuel ratio for spark ignition engines. As shown in the

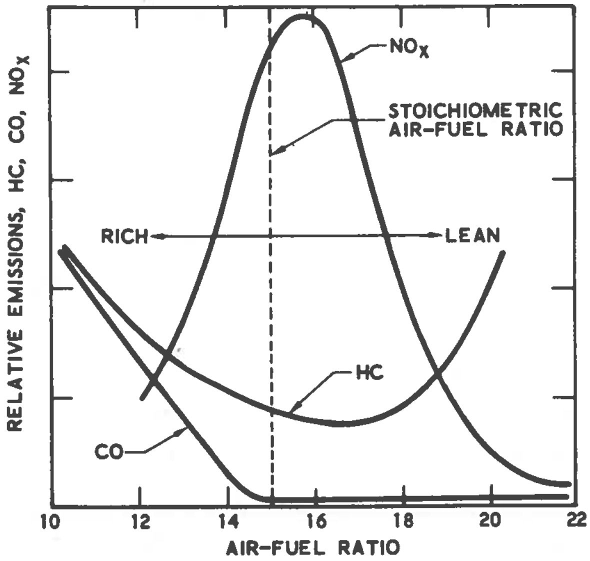


FIGURE 2-2 EFFECT OF AIR/FUEL RATIO ON EMISSION LEVELS; SPARK-IGNITION ENGINE (Ref. 2-5)

figure, the air/fuel ratio has a pronounced effect on NO_x, HC, and CO. Adjustment to a fuel-rich mixture results in low NO_x emissions, accompanied by an increase in HC and CO as well as fuel consumption, while lean mixture operation substantially reduces these pollutants and improves fuel economy. However, in gasoline engines, air/fuel ratios leaner than approximately 18 result in operational difficulties unless specialized techniques, such as charge stratification, are used.

2.2.3.1 Carburetor Systems

2.2.3.1.1 Mixture Preparation

The function of the carburetor is to provide the proper air/fuel mixture ratio, mix the air and fuel as intimately as possible, and provide a means for regulating engine power. The performance of these functions is complicated by the necessity of accomplishing them over a wide range of engine speeds and vehicle operating modes such as warmup, idle, acceleration, deceleration, cruise, and WOT. A typical simplified air/fuel ratio versus air flow distribution is presented in Figure 2-3 showing the idle and low-load regime (AB), the economy or cruise regime (BC), and the full load WOT regime (DE).

During idle and low-load operation, the throttle is near the closed position, and the engine requires a rich mixture as shown by line AB in Figure 2-3. Under these conditions, the pressure in the intake manifold is far below atmospheric, while the pressure at the end of the exhaust stroke is always close to atmospheric. When the intake valve opens, a higher pressure exists in the cylinder than in the intake manifold, causing the exhaust gas to expand into the intake manifold. Later, the exhaust gases are drawn back into the cylinder on the intake stroke along with a portion of the fresh charge, resulting in an overall mixture containing a substantial amount of exhaust gas. Rich mixtures are required to ensure proper combustion of the diluted charge. The dilution is maximum under no-load conditions and is gradually reduced with increasing load.

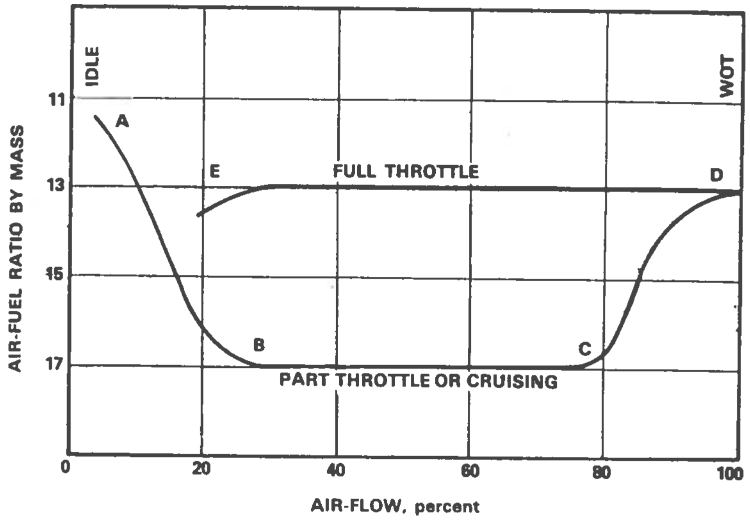


FIGURE 2-3 AIR/FUEL RATIO REQUIRED BY A SPARK IGNITION ENGINE AT VARIOUS AIR FLOW RATES

At medium loads and cruise conditions, the throttle opening is sufficiently large that the effect of dilution is negligible, and a lean mixture is used to provide optimum fuel economy (line BC in Figure 2-3). An air/fuel ratio in the range of 16 to 18 might be the best compromise for the various part-load requirements of a modern spark ignition engine.

Under high-load conditions when the throttle valve is opened 75 percent or more, a rich mixture is required to give maximum power. When the speed is reduced at WOT by increasing the load, the air/fuel ratio requirement passes from D to E, ideally at a constant charge ratio.

The principal transient engine operating conditions are cold start, warmup, and acceleration. To compensate for fuel condensation effects in the intake manifold during engine cold start, carburetors have always been adjusted to initially provide a rich air/fuel mixture by means of a choke. While mixture enrichment is also required during engine warmup, the degree of richness is progressively reduced in modern carburetors as fuel vaporization improves with increasing engine temperature.

Unless some supplementary fuel is added to the mixture during acceleration, a momentary lean condition will result, arising from both the inertia of the liquid fuel in the manifold and the decrease in vaporization of the fuel at higher manifold pressures. An acceleration pump is used to provide the additional fuel.

2.2.3.1.2 Carburetor Design and Operation

The basic elements of a typical single-barrel, triple-venturi carburetor are illustrated in Figure 2-4, showing the main metering system, idling system, and acceleration system.

The main metering system, implemented by the main metering orifice, the main metering jet, and the venturis (A, B, C), provides the air/fuel mixture required for cruise conditions. The economizer, which is a supplementary metering orifice modulated by engine load, meters fuel for both cruise and full load conditions.

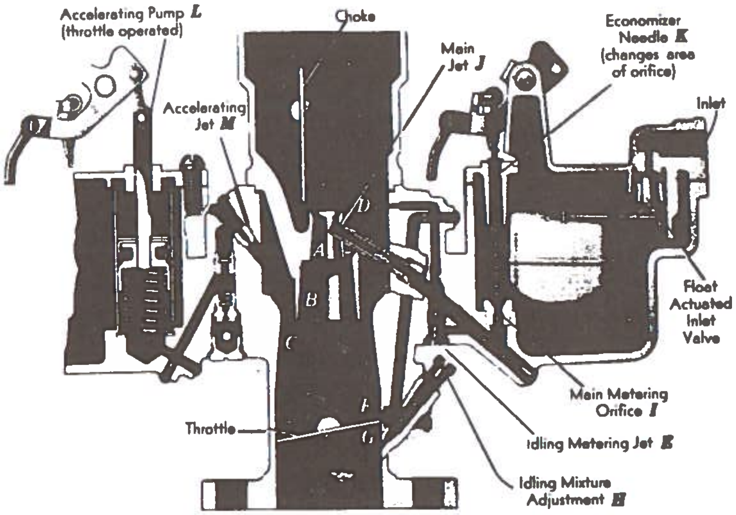


FIGURE 2-4 CARTER DOWNDRAFT TRIPLE-VENTURI CARBURETOR WITH HIGH-LOAD ENRICHING DEVICE (Ref. 2-6)

The idle system, which provides a rich mixture, consists of the idle metering jet, the idle mixture adjustment screw, the primary air bleed, and the off-idle bleeds (F, G). To provide instantaneous response of the engine to a sudden increase in power demand, the carburetor is equipped with an accelerating system consisting of an accelerator pump.

2.2.3.1.3 Carburetor Subsystems and Devices

In addition to the basic carburetor metering systems described in the previous section, modern carburetors use various subsystems and devices to aid in implementing the desired metering profile. These subsystems and devices are required both to meet transient operational conditions and exhaust emission control requirements.

2.2.3.1.3.1 Cold-Start Control Subsystem

From the viewpoint of limiting HC and CO emissions, the cold start, or choke control, subsystem of a carburetor is of primary importance. The cold start of a spark ignition engine requires substantial fuel enrichment at the carburetor to assure that an adequate amount of fuel is delivered to each cylinder after allowing for reduced cold temperature fuel vaporization and intake manifold condensation effects. Conversely, an overly rich charge coupled with combustion chamber quench effects leads to high HC and CO concentrations in the exhaust. In addition, if supplemental enrichment is maintained too long after startup, the fuel-rich charge causes high HC and CO emissions as indicated in Figure 2-2. To alleviate these problems, sophisticated choke configurations are used in modern carburetors. Typically, a coiled bimetallic spring is used as the basic control element to position the choke valve, which is located just inside of the air inlet of the carburetor barrel as shown in Figure 2-5. For a cold engine condition, the bimetallic spring causes the choke to block the carburetor air inlet area. During startup, the choke valve opens slightly as inflowing air pumped by the engine partially overcomes the torque provided by the cold bimetallic spring. Since the choke valve is nearly closed, a high vacuum acts on the main fuel jet, thereby causing a relatively high fuel flow and the fuel enrichment required to start the cold engine.

As the engine starts, manifold vacuum is applied to a kick-or-vacuum break diaphragm, which opens the choke further. Simultaneously, heat is applied to warm the bimetallic spring and to allow the choke to open further. The attendant lower vacuum operating on the main fuel jet of the carburetor results in a lower fuel flow rate and leaner air/fuel mixtures.

The heat used to warm the bimetallic spring of the choke valve may be obtained from any of several sources, and, in some cases, more than a single heat source is used. Typically, the bimetallic spring is heated by exhaust manifold heat or engine coolant. In addition, electric-assist heating of the spring is provided in many late model carburetors.

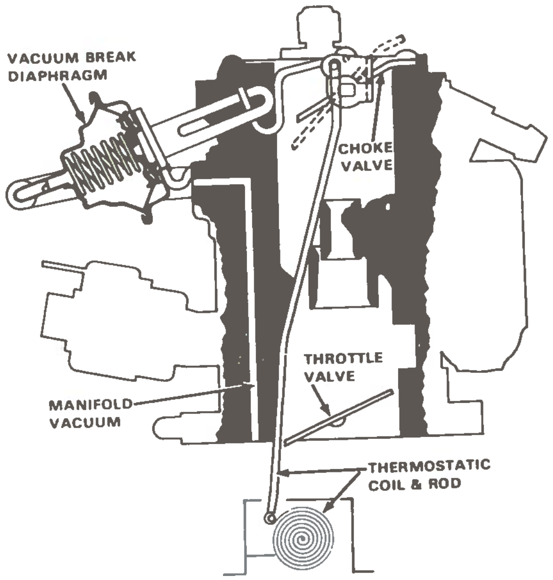


FIGURE 2-5 TYPICAL CARBURETOR CHOKE SYSTEM

2.2.3.1.3.2 Auxiliary Subsystems and Devices

A number of emissions-related devices have been added to the carburetor since the imposition of exhaust emission regulations. These devices generally are intended to assist in the control of HC and CO emissions during transient engine conditions and usually fall into one of several general classifications according to the engine operating phase in which they are active.

Deceleration control is implemented by a throttle positioner, a manifold air bleed device, or throttle lever dashpot. The throttle positioner incorporates a solenoid and speed sensor to limit throttle closure to the fast-idle position during high-speed vehicle deceleration. The manifold air bleed maintains fast-idle speed during deceleration via a manifold vacuum-actuated valve. The valve essentially implements a throttle air bypass during periods of high manifold vacuum levels associated with high-speed deceleration. Throttle dashpots are simple viscous devices which limit the rate of throttle closure and may be used alone or in conjunction with other deceleration control devices.

Many late model engines incorporate a throttle closer, a hot idle compensator, an idle limiter cap, and an altitude compensator. The throttle closer is implemented by a solenoid and a speed sensor which closes the throttle beyond the normal curb idle position when the ignition key is in the off position, thus denying the engine an adequate air supply for continued operation.

The hot idle compensator consists of a temperature-sensitive bimetal spring actuating an air valve to supply additional air below the carburetor-throttle plate. This device, which is frequently used in conjunction with air conditioning, increases engine idle speed resulting in lower engine operating temperatures. The idle limiter is designed to provide close idle air/fuel ratio control with the objective of controlling HC and CO exhaust emissions at idle. The altitude compensator adjusts for the mixture enrichment associated with high-altitude engine operation. The unit consists of a bellows, which expands with increasing altitude and moves a tapered needle into an orifice to reduce the fuel in the carburetor air/fuel passages. In general, altitude compensators are not widely used and have been dropped from some engine lines in recent years.

2.2.3.2 Fuel Injection Systems

Two types of fuel injection systems, manufactured by Bendix and Bosch, are currently used in one domestic and several foreign automobiles. These systems are of the manifold injection type using either continuous or timed-pulse injection of fuel. Currently, the application of fuel injection is limited to a few manufacturers.

2.2.3.2.1 Timed Injection Systems

The Bosch L-Jetronic timed injection system is designed to meter fuel according to the same basic air/fuel profile as the carburetor (Figure 2-3). Implementation is based on electronically sensing engine speed and engine inlet air flow rate. These variables are provided to an electronic control module which calculates the proper amount of fuel to be injected into each cylinder. Also, the module sends electrical signals to open and close the fuel injector valves located in the intake manifold immediately adjacent to each engine cylinder intake valve. Fuel is provided to the injector valves at a constant pressure, and the amount of fuel injected depends on the time period the valves remain open. Thus, fuel flow control to meet changing engine requirements is implemented by providing the injectors with injection time signals of varying length.

Additional fuel and air for cold start enrichment and fast idle are furnished by a single cold start injector and an auxiliary air passage. Both of these devices are modulated by engine temperature in a manner which reduces their effect with increasing temperature.

Emission control devices incorporated into the fuel injection system are much less extensive than in the previously discussed carburetor systems. In a sense, the fuel injection system by itself is an emission control device, at least to the extent that it provides improved cylinder-to-cylinder mixture distribution relative to the carburetor. In addition, some fuel injection systems are equipped with deceleration control devices designed to reduce HC and CO emissions during vehicle deceleration.

2.2.3.2.2 Continuous Fuel Injection

The Bosch K-Jetronic fuel injection system is an all-mechanical system which modulates fuel flow on a continuous basis according to sensed engine air flow rate. The air flow sensor consists of a plate in a vertical air venturi. Displacement of the plate from its rest position, which is proportional to the engine intake air flow rate, is used to control the fuel flow rate to the engine. The mechanism used to accomplish air flow rate modulation of fuel flow rate consists of a lever connecting the sensor plate and a fuel control plunger. As air flow rate increases, the plunger progressively uncovers slots in a cylinder through which fuel flows to individual injectors near each engine cylinder intake valve. Fuel flow control is maintained by balancing the fuel pressure acting on the plunger and the air flow forces at the air sensor plate. This results in a near-linear air/fuel ratio-versus-air flow rate characteristic.

Mixture enrichment during cold start is obtained by a separate injection valve which operates only during engine cranking. After the engine is running, a bimetallic engine temperature sensor modulates fuel control pressure to provide added enrichment until normal operating temperature is attained. Similar to the timed fuel injection system, additional air is provided for fast idle by a bimetallic controlled auxiliary air passage.

2.2.4 Ignition System

The primary requirement of the ignition system is to provide a sufficiently high voltage to the spark plugs for air/fuel mixture ignition. In the past, this has been accomplished by conventional breaker-point ignition systems which are inexpensive, simple to maintain, and, until recently, generally regarded as entirely adequate for automobile applications. However, as exhaust emission control standards have become increasingly stringent, the need for an improved ignition system has become more apparent. This has led to the development of a number of advanced systems which are currently used by several manufacturers.

2.2.4.1 Conventional Ignition System

The conventional 12-volt ignition system is made up of a battery, switch, coil, resistor, distributor, spark plugs, and associated wiring as illustrated in Figure 2-6. In this system, the voltage supplied to the spark plugs exceeds the spark plug breakdown voltage by some margin to compensate for wear factors, such as deterioration of breaker points and spark-plug electrodes, fouling of spark plugs, and cyclic variations in air/fuel mixture ratio.

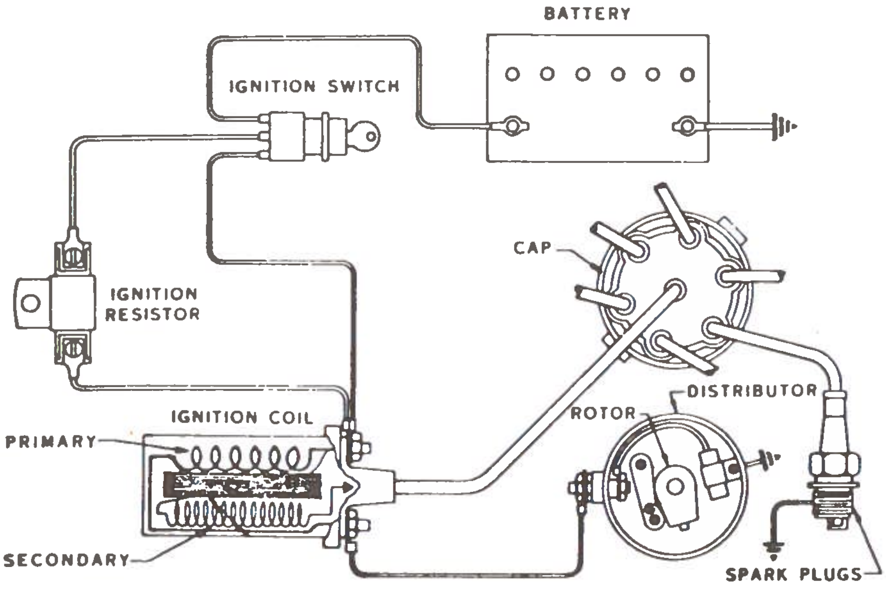


FIGURE 2-6 CONVENTIONAL 12-V IGNITION SYSTEM

The coil is a pulse-type transformer which steps up the 12-volt battery voltage to the high voltage necessary to fire the spark plugs. The distributor points interrupt the current through the primary windings of the coil causing the magnetic field to suddenly collapse, thus producing a high-voltage output in the secondary circuit of the coil. The rotor directs this high voltage to the appropriate spark plug. Centrifugal and vacuum advance mechanisms within the distributor provide variable timing of the spark, consistent with engine speed and road load conditions.

2.2.4.2 Advanced Ignition Systems

Advanced ignition systems attempt to alleviate the wear problems of the conventional system by either substituting electronic for mechanical devices or by using the electronic devices to modify the operation of the existing system. In most cases, the goal is a shorter elapsed time to peak spark voltage, and more constant voltage at the 35-kV level from low-to-high engine rpm. The high-voltage or high-energy feature coupled with a multiple-spark capability in some systems is obtained by altering the basic parameters of the electrical circuit.

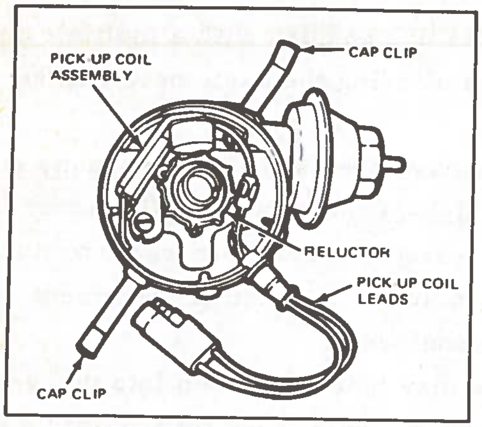
Electronic ignition systems have been available for many years, initially developed for special purpose, high-performance applications. As this segment of the industry matured, these systems found their way into the automotive aftermarket and, presently, are included as original equipment on all domestic and some imported automobile engines.

Electronic ignition systems may be categorized into two general types: inductive and CD systems. In general, both types incorporate a breakerless feature to eliminate problems associated with breaker point wear.

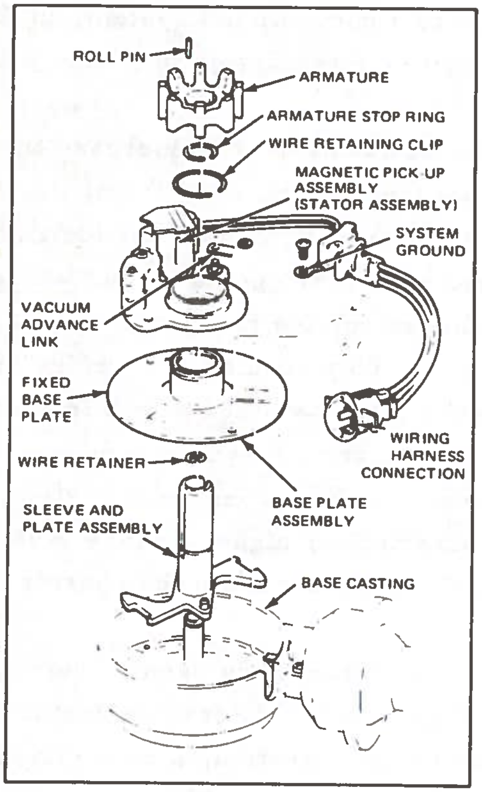
In the inductive breakerless system, the spark is triggered by a solid-state switch which is actuated by a magnetic pickup attached to the distributor shaft. This system is similar to a conventional system, in that it produces a high-voltage output from the coil by interrupting the current in the primary circuit.

CD systems typically consist of a converter to increase the battery voltage, an energy storage element (capacitor), a switching device (silicon controlled rectifier, or SCR), and an output transformer (coil). The breaker points are frequently retained and used to trigger a circuit which discharges the capacitor, causing the primary voltage in the coil to rise from 0 to about 400 volts in approximately 2 μsec. This results in a sudden rise in the strength of the magnetic field to produce a high-voltage output from the secondary winding of the coil. In this manner, the CD system achieves both higher voltage and a much faster rise time than the conventional system, providing improved engine starting characteristics, higher voltage in the high-speed regime, and increased spark plug life resulting from the shorter energy release period.

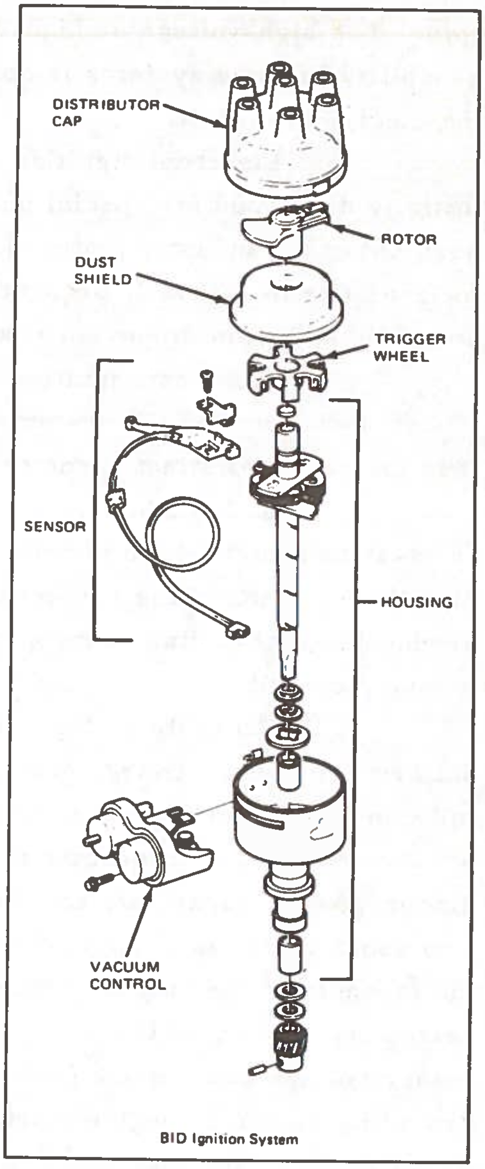
Typical inductive ignition systems currently used by domestic automobile manufacturers are shown in Figure 2-7. Noteworthy features include an armature/starter assembly in the Ford system, a reluctor/pickup coil assembly in the Chrysler system, and a trigger wheel/sensor in the AMC system. These systems do not differ significantly from the electronic ignition devices which have been offered in the automotive aftermarket for a number of years.



Chrysler Electronic Ignition System (EIS)



Ford Solid State Ignition (SSI) System



AMC Breakerless Inductive Discharge (BID)

FIGURE 2-7. TYPICAL ELECTRONIC IGNITION SYSTEMS

2.2.4.3 Ignition Timing and Spark Advance Modifications

Ignition timing has a strong effect on the HC and NO_x exhaust emissions of spark ignition engines. In general, these emission species decrease substantially with increasing ignition timing retard. In the case of NO_x, the reduction mechanism is one of lowering the peak cycle flame temperature during combustion by retarding the ignition timing. Since the formation of NO_x is exponentially dependent on peak cycle flame temperature, the reduction in NO_x can be substantial. The reduction of HC by means of ignition timing retard is caused by the continuing oxidation of unburned species in the exhaust system, resulting from late ignition of the combustible charge in the cylinder.

However, as shown in Figure 2-8, ignition timing retardation has a highly negative impact on fuel economy. Particularly harmful is the reduction or deletion of vacuum advance in the part-throttle cruise condition. For maximum fuel economy, considerable ignition advance is required to allow sufficient time for propagation of the slow burning flame front associated with lean air/fuel ratios used during cruise. However, some retard from optimum spark advance settings is generally required to meet prevailing emission regulations. Retarding the ignition timing from the optimum fuel economy points generally requires fuel delivery system recalibration to retain acceptable power and driveability characteristics, and this can cause further reduction in fuel economy.

2.2.4.3.1 Basic Timing and Centrifugal Advance

With the advent of emission control regulations in 1966 in California, basic timing has been reduced to control HC and CO emissions at idle, as shown in Figure 2-8. With retarded timing, a wider throttle-plate opening is required to maintain a given idle speed permitting the use of leaner idle air/fuel ratios. In addition, the centrifugal advance has been reduced particularly in the low-to-medium speed range corresponding to the Federal city-driving cycle. In general, this has provided emission control accompanied by lower fuel economy. All manufacturers have incorporated revised basic and centrifugal advance schedules relative to the schedules used in uncontrolled engines.

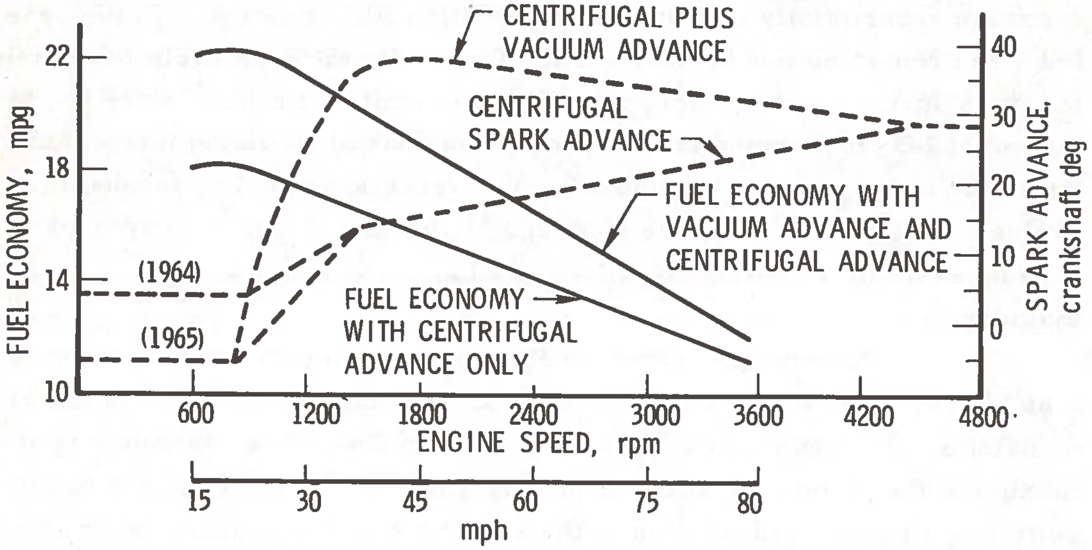


FIGURE 2-8 EFFECTS OF CENTRIFUGAL AND VACUUM SPARK ADVANCE ON PERFORMANCE (Ref. 2-6)

2.2.4.3.2 Vacuum Advance

Similar to the centrifugal advance, the vacuum advance schedules have been modified during the past few years. Most of the devices used to implement these modifications can be characterized according to their impact on a specific mode of vehicle operation. In almost all cases, their implementation represents an attempt to resolve the difficult tradeoff which exists between fuel economy and exhaust emission control via retarded ignition timing.

Vacuum advance is implemented by the distributor vacuum unit, which consists of a spring-loaded diaphragm and a vacuum chamber. The movement of the diaphragm, which determines the amount of vacuum advance, is controlled by a carburetor port vacuum or intake manifold vacuum. In the ported vacuum system, the vacuum signal is provided by a small port located in the carburetor body slightly above the closed position of the throttle plate.

The placement of the vacuum port relative to the throttle plate largely determines the vacuum advance-versus-throttle position profile. Since the advent of emission control standards, the location of the port has been varied slightly in conjunction with the overall emission control system optimization procedure. At idle, the port is subjected to atmospheric pressure, and no vacuum advance is obtained. This results in lower HC emissions at idle because of later ignition of the charge and continued oxidation of the combustion gases in the exhaust system. Conversely, in manifold vacuum-actuated systems, a high vacuum signal is obtained at idle, resulting in high spark advance and increased exhaust emission levels.

As the throttle is opened, it uncovers the vacuum advance port and the high-velocity air flow between the small passage formed by the carburetor throttle blade, and the carburetor body causes a high vacuum signal to be developed at the port, which is transmitted to the vacuum advance diaphragm. This results in improved engine fuel economy characteristics.

With increasing engine load, less spark advance is required for optimum combustion because of the associated increase in flame speed in the combustion process. The reduction in spark advance is implemented by the location of the vacuum advance port which, under these conditions, provides a smaller vacuum signal because of the lower local flow velocities associated with further throttle opening. A typical overall vacuum advance profile is shown in Figure 2-9 as a function of throttle position.

2.2.4.3.3 Vacuum Retard

Vacuum retard devices are used on many late model engines as a means of providing HC control at idle and during closed throttle deceleration. These devices are similar to vacuum advance systems and are mechanized with an additional vacuum-actuated distributor diaphragm which receives its vacuum signal from a port located slightly below, rather than above, the closed-throttle position. This causes development of a maximum vacuum signal and maximum retard at idle or during closed throttle deceleration. As the throttle is opened slightly, the vacuum signal is sharply reduced in most installations, and vacuum retard is quickly eliminated. However, in some cases, an auxiliary device is used which inhibits vacuum advance by delaying the reduction of

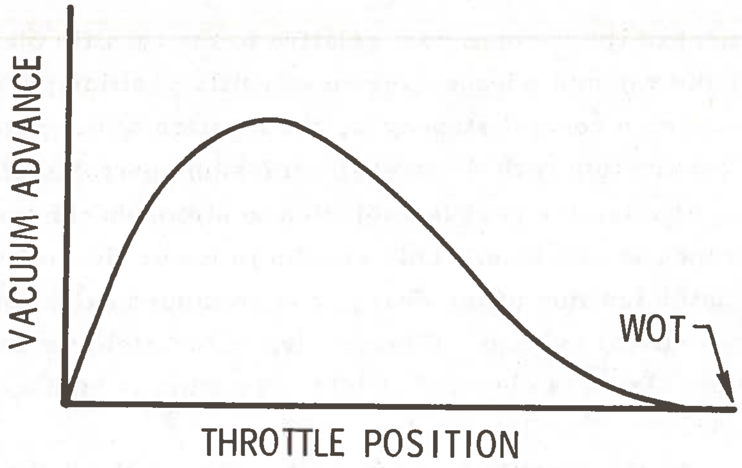


FIGURE 2-9. STEADY-STATE PORTED VACUUM ADVANCE VERSUS THROTTLE POSITION AT CONSTANT ENGINE LOAD

vacuum retard as the throttle is opened. This causes retard to be partially effective into the part-throttle regime.

2.2.4.3.4 Transmission-Controlled Spark

TCS is a method of selectively eliminating vacuum advance during certain modes of vehicle operation. Typically, on manual transmission vehicles, a solenoid-actuated vacuum advance defeat is implemented in the lower gears. On automatic transmission vehicles, vacuum advance is eliminated in the low-to-medium vehicle-speed regimes. The net effect of using TCS is one of reduced NO_x emissions and reduced fuel economy. TCS has been rather widely used by domestic manufacturers; however, it is currently used to a lesser degree since EGR, beginning in 1973, has succeeded TCS as the primary NO_x control method.

2.2.4.3.5 Coolant Temperature Spark Modulation

In modern automobile engines, several control systems are modulated in an on-off manner to improve specific aspects of vehicle performance, such as driveability and engine cooling, while maintaining low exhaust emissions over emission-critical portions of the Federal driving cycle.

Coolant temperature is frequently used to implement the discrete modulation of ignition advance and retard. As an example, vehicles using TCS often incorporate a coolant temperature override device which restores vacuum advance for operation in the low gears during engine warmup. This improves vehicle driveability at cold engine temperatures without compromising the NO_x control capability of TCS after engine warmup.

In some installations, a coolant temperature override device is used to eliminate vacuum retard at idle and when the engine temperature is high. This tends to cool the engine and have a positive effect on emissions as hot engine operation leads to overly rich air/fuel ratios and, consequently, high HC and CO emissions at idle.

2.2.5 Exhaust Gas Recirculation

While intake-exhaust valve overlap has been shown to be an effective technique for NO_x control in internal combustion engines, it has a number of inherent disadvantages, such as rough idling and reduced low-speed torque. These disadvantages, along with the fact that NO_x reduction is only required when the engine is under load, suggest that a modulated form of charge dilution better serves the requirements of NO_x control. EGR is a system which serves that requirement.

In principle, current EGR systems consist of an EGR valve which meters the exhaust gas recirculated into the engine intake as a function of engine load and speed. The position of the EGR valve is mechanically controlled by the throttle position or by a diaphragm which is modulated by a signal originating at the carburetor EGR port, the carburetor venturi, or the exhaust manifold. In engines with fuel injection, the EGR signal is taken from either the intake system or the exhaust manifold. The EGR flow rate provided at different engine operating conditions is impacted by a number of factors, including the effective EGR valve area, the exhaust manifold pressure, the intake manifold pressure, and the placement of the EGR vacuum port in the carburetor body relative to the location of the throttle.

Ideally, an optimal EGR system meters exhaust gas in direct proportion to engine load with, perhaps, an EGR defeat mechanism at WOT to retain full performance for passing maneuvers. This requires the use of a system control parameter which is readily available and is proportional to engine load.

Five types of EGR are currently used by the automobile manufacturers: (a) ported vacuum-modulated EGR, (b) intake manifold vacuum-modulated EGR, (c) venturi vacuum-modulated EGR, (d) exhaust backpressure-modulated EGR, and (e) throttle position-modulated EGR. These systems are briefly described in the following paragraphs.

2.2.5.1 Ported Vacuum-Modulated EGR

Ported EGR systems are modulated by a vacuum signal obtained from a port located in the carburetor slightly above the closed position of the throttle valve. The vacuum-versus-throttle position signal is essentially the same as the ported vacuum ignition advance signal described previously. When the throttle is closed, such as at idle, there is no vacuum to the EGR valve and, therefore, no EGR. As the throttle opens, partial vacuum is created at the EGR vacuum port, opening the EGR valve, and causing the recirculation of exhaust gas. Further opening of the throttle leads to lower vacuum levels at the port until, at WOT, vacuum is too low to hold the EGR valve open and recirculation ceases. While this system provides EGR modulation which is only roughly proportional to engine load in the low-load regime, it is reasonably effective.

2.2.5.2 Intake Manifold Vacuum-Modulated EGR

Intake manifold vacuum-modulated EGR is currently used in full size sedans and station wagons marketed by GM in California. This system features a dual diaphragm, spring-loaded EGR valve designed to maintain proportionality between EGR and engine load over a wide range of engine operating conditions. In this system, the EGR valve is made up of two diaphragms which are connected by a spacer. Manifold vacuum is applied to the chamber between the two diaphragms. The upper diaphragm has a larger effective area than the lower diaphragm, and the load caused by manifold vacuum acting between the two diaphragms is additive to the spring load. Thus, as engine load increases, manifold vacuum decreases, and the combined force of the spring and the diaphragms causes the valve to open further, providing more EGR at high engine loads.

2.2.5.3 Venturi Vacuum-Modulated EGR

Venturi vacuum-modulated EGR is based on using a relatively weak vacuum signal obtained from the carburetor venturi or the inlet system in fuel injected engines. The weak signal is amplified by a vacuum amplifier using an accumulator charged by manifold vacuum, and the amplified signal is used to control the EGR valve as in the ported system. To defeat EGR at WOT, a relief valve is provided to dump the output EGR signal of the amplifier when venturi vacuum is equal to or greater than intake manifold vacuum. Relative to the ported vacuum system, the venturi vacuum system has the potential of providing EGR flow rates proportional to engine flow rate over a wide range of engine operating conditions.

2.2.5.4 Exhaust Backpressure-Modulated EGR

Backpressure EGR systems currently represent the most sophisticated approach to meter exhaust gas in proportion to engine load. These systems feature a backpressure sensor which controls a valve placed in series between the EGR valve and its source of actuating vacuum. The exhaust backpressure modulates the backpressure valve which in turn modulates the actuating vacuum to the EGR valve. As exhaust gas backpressure is a good measure of engine load, the system more closely approaches the desired EGR versus engine load characteristic than systems based directly on ported or venturi vacuum signals.

2.2.5.5 Throttle Position-Modulated EGR

Throttle position-modulated EGR uses a mechanical linkage arrangment to modulate EGR flow roughly in proportion to engine load. Provisions are made to eliminate EGR at idle, during closed throttle deceleration, and at WOT.

2.2.5.6 Coolant Temperature and Speed EGR Modulation

In addition to the vacuum, pressure, and position techniques noted above, most EGR systems incorporate engine coolant modulation which eliminates EGR for improved vehicle driveability during engine warmup when NO_x formation rates are low. Speed modulation is used in some engines to deactivate EGR for vehicle speeds outside a predetermined range.

2.2.5.7 Vehicle Performance With EGR

While EGR is effective in reducing NO_x, early studies indicated it can exact performance penalties in terms of fuel economy and driveability (Ref. 2-7). More recent investigations indicate that if the suppression of NO_x is the sole emission control criterion, the use of EGR can result in large decreases in NO_x emissions with little or no decrease in fuel economy (Ref. 2-8). To accomplish this, spark timing must be set at minimum for best torque (mbt) and this leads to high HC emissions. Spark timing retard relative to the mbt position can be used to alleviate the HC emission problem, but this in turn will result in a fuel economy loss.

As indicated, control of exhaust emissions is a systems problem demanding simultaneous control of three pollutant species. Current emission control practice usually incorporates (a) some spark retard relative to mbt to satisfy HC control requirements, (b) the use of EGR to control NO_x emissions, and (c) an air/fuel ratio slightly richer than would be used in a system without EGR, but lean enough to preclude excessive CO emissions. The richer mixture assures good driveability with EGR and air as opposed to pure air as a fuel diluent.

In addition to providing NO_x control, EGR has been shown to be an effective engine knock suppressant, particularly for rich air/fuel mixture operation. Therefore, the engine compression ratio can be increased, resulting in partial recovery of the fuel-economy losses caused by the use of EGR.

2.2.6 Secondary Air Injection

Secondary air injection into the engine exhaust ports has been widely used as an independent control device for the suppression of HC and CO emissions since 1966. Currently, it is often used in conjunction with after-treatment devices, such as catalytic converters and thermal reactors which require the presence of O_2 to promote the oxidation of HC and CO.

The hardware which makes up current air injection systems typically consists of an engine-driven air pump, hoses, manifolds to deliver the air to each exhaust port, and a series of valves to prevent backfire and to provide relief to the pump when the engine is operating at high speeds and peak loads. In these air systems, air flow modulation is based solely on engine speed, and demand variations caused by throttle setting are ignored.

Fuel economy and power loss penalties associated with the operation of air injection systems are negligible as shown in Figure 2-10 (Ref. 2-9), although pump noise and durability are occasionally cited as problem areas.

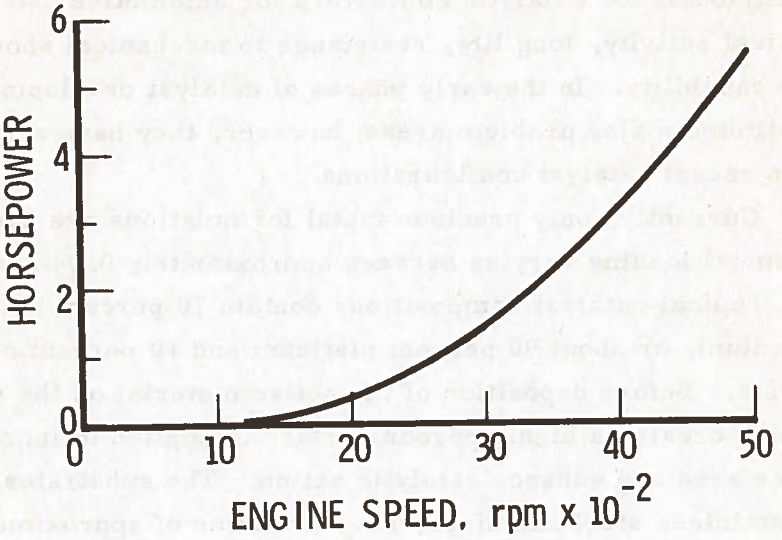


FIGURE 2-10. SECONDARY AIR PUMP POWER REQUIREMENTS (Ref. 2-9)

2.2.7 Oxidation Catalyst

A catalytic converter is a device containing a catalyst material which promotes chemical reactions which otherwise occur very slowly. Those catalysts which promote the oxidation of HC and CO into CO_2 and H_2O are referred to as oxidation catalysts. Great efforts have gone into the development of both pelletized and monolithic catalysts for automotive applications, and literally hundreds of different active metal formulations have been tested, including base metal, precious metal, and combined base metal/precious metal configurations. Oxidation catalysts require excess O_2 for HC and CO conversion, which is accomplished by operating the engine sufficiently lean or by adding secondary air in the engine exhaust system upstream of the catalyst. To date, the latter approach has been used almost exclusively.

Specific configurations of catalysts and catalytic converters vary widely. One popular approach is to use a monolithic coated substrate contained in a cylindrical shell. Another approach is to use a pelletized form of catalyst held in place by interior louvered members within an outer container. Necessary attributes for catalytic converters for automotive use include sufficient chemical activity, long life, resistance to mechanical shock, and high-temperature capability. In the early phases of catalyst development, these factors constituted major problem areas; however, they have essentially been eliminated in recent catalyst configurations.

Currently, only precious metal formulations are used with the total active metal loading varying between approximately 0.04 and 0.11 troy oz/vehicle. Typical catalyst compositions contain 70 percent platinum and 30 percent palladium, or about 90 percent platinum and 10 percent other precious metal elements. Before deposition of the active material on the substrate, a washcoat which creates a highly porous surface is applied to increase the substrate surface area and enhance catalytic action. The substrates, which are housed in a stainless steel container, have a volume of approximately 150 to 250 cu in.

From a fuel economy point of view, catalysts have an indirect but favorable impact. By shifting the HC and CO emission control burden from the engine to an after-treatment device, greater freedom is provided in optimizing other engine controls, such as the ignition system and the carburetor.

2.2.8 Thermal Reactors

A thermal reactor is a chamber which replaces the conventional engine exhaust manifold. The chamber is sized and configured to increase the residence time of the gases and permit further chemical reactions, thus reducing HC and CO concentrations in the exhaust. The thermal reactor embodies a double-walled and insulated configuration, using port liners to direct the exhaust gases to its inner core section. In some instances, baffles and/or swirl plates are used to increase flow turbulence for the purpose of improving HC and CO conversion.

There are two different types of thermal reactors: (a) the rich thermal reactor (RTR); and (b) the lean thermal reactor (LTR). The RTR is designed for fuel-rich engine operation. As the exhaust from the cylinders contains large quantities of HC and CO, secondary air supplied by a pump is injected into the exhaust ports upstream of the reactor to permit further oxidation of these species. Because of the chemically reducing atmosphere and lower combustion temperatures, the amount of NO_x formed in RTR-equipped engines is reduced also. NO_x emission levels as low as 0.5 g/mi have been achieved in experimental RTR configurations; however, this improvement is accompanied by fuel economy penalties of up to 20 percent. Aside from the losses in fuel economy because of operation with rich air/fuel ratios, a small additional penalty is incurred as a result of the power required to drive the secondary air pump.

The LTR which is used in conjunction with an engine operated with lean mixtures does not require the use of a secondary air system. In this case, the raw HC and CO emissions are much lower than for the RTR, while NO_x is somewhat higher. Little chemical heat is generated in the reactor, and its temperature is governed primarily by the sensible heat in the exhaust gas. As a result, the oxidation of HC and CO in the LTR proceeds at lower temperature than in the RTR.

2.2.9 Crankcase and Evaporative Emission Control

Both the crankcase and evaporative emission control systems are relatively simple in design, showing only minor differences between the various manufacturers. Complete control of crankcase emissions has been achieved since 1968 by means of a closed loop system, replacing the open loop and draft tube ventilation systems used in earlier model years. In well-maintained engines, the crankcase emission control system has little impact on vehicle performance, fuel economy, and driveability.

Evaporative emission control systems have been in use since 1970 in California and since 1971 nationwide. These systems feature a charcoal canister which is designed to temporarily store fuel vapors released from the fuel tank and the carburetor bowl after engine shutdown. The canister is purged when the engine is running.

In general, the effectiveness of evaporative emission control systems is more than adequate to meet current emission regulations. With few exceptions, the evaporative HC emissions of the 1976 model certification vehicles are below 1 g/test as compared to 2 g/test permitted by current regulations. The effect of evaporative emission control on vehicle fuel economy is negligible because of the relatively small amounts of fuel vapor handled by the system.

2.2.10 Advanced Control Techniques

2.2.10.1 Lean Burn Concept

The fuel economy and emission advantages associated with lean air/fuel mixture operation have long been recognized. However, the implementation of lean burn engines meeting stringent exhaust emission regulations is inhibited by the lack of advanced ignition, intake, and carburetor systems capable of providing sufficiently close control of spark timing and mixture ratio.

The Chrysler 400-CID lean burn engine introduced in 1976 is the first production engine of its type meeting the 1976 Federal emission standards without the use of a catalyst or air pump, while providing a 5 percent improvement in fuel economy relative to equivalent conventional engines. The engine, which operates at air/fuel ratios of about 18, features a computer-controlled spark advance system providing optimum spark advance in terms of emissions, fuel economy, and driveability under all engine operating conditions in accordance with a predetermined schedule. The control system incorporates seven sensors which monitor important engine parameters, including the condition of the engine at start, engine speed, intake manifold vacuum, throttle position, rate of change of throttle position, intake air temperature, and coolant temperature. The output of the sensors is transmitted to the central computer which instantaneously and continually determines optimum spark timing.

Relative to conventional engines, the advantages of the Chrysler lean burn engine include more precise spark control, better fuel economy, and lower initial and operating costs resulting from the deletion of the catalyst and air pump, and from the acceptability of leaded gasoline.

2.2.10.2 Reduction Catalyst

While the development of catalysts capable of decomposing NO_x in the presence of excess oxygen have been unsuccessful, a number of reduction catalysts have been developed which exhibit good NO_x reduction efficiency and durability when operated with rich air/fuel mixtures. The most successful developments to date, exemplified by the Questor and Gould systems, incorporate a nickel-based catalyst formulation deposited on a monolithic substrate.

To provide close control of the oxygen concentration of the exhaust gases entering the reduction catalyst, the Gould system incorporates a small monolithic precious metal oxidation catalyst upstream of the reduction catalyst. Conversely, the Questor system employs a small thermal reactor in place of the oxidation catalyst. HC and CO control is achieved in the two systems by means of a second oxidation catalyst (Gould) or a second thermal reactor (Questor) installed downstream of the reduction catalyst.

The fuel economy advantage of reduction catalyst systems, relative to conventional NO_x abatement techniques, is particularly evident at low NO_x levels. In this regime, the reduction catalyst permits the use of more optimal spark timing, and a reduction or even complete elimination of EGR, resulting in more efficient engine operation and better vehicle fuel economy.

2.2.10.3 Three-Way Catalyst

A number of investigators, including Universal Oil Products (UOP), Engelhard Industries, and Volvo, have demonstrated the feasibility of simultaneous control of the three currently regulated pollutant species; HC, CO, and NO_x, in a single-bed catalyst. However, to maintain the required CO and NO_x levels in the catalyst feed gas, stoichiometric air/fuel mixture operation of the engine is required. Typically, the air/fuel ratio excursions must be limited to less than ± 0.7 percent. Of course, this is beyond the capability of conventional carburetor and fuel injection systems. It requires the use of a closed loop, feedback control system.

Recently, Volvo has successfully completed EPA 4000-mile certification tests on four of its fuel-injected, 4-cylinder vehicles equipped with a three-way catalyst and an exhaust gas-oxygen sensor (λ -sensor). On average, the emissions from these vehicles, extrapolated to 50,000 miles are 0.2 g/m HC, 2.8 g/m CO, and 0.17 g/m NO_x, which is substantially lower than the 1976 statutory standards (0.41 g/m HC, 3.4 g/m CO, and 0.4 g/m NO_x). These emissions are accompanied by a 10 percent improvement in fuel economy relative to the Volvo fuel-injected 1976 California certification vehicles.

The λ -sensor, developed by Robert Bosch of Germany, features a solid electrolyte O_2-sensing cell which consists of two platinum electrodes deposited on the outside and inside surfaces of a zirconia tube. The inside electrode is in contact with atmosphere, whereas the outside electrode is in contact with the engine exhaust gas. At stoichiometric, the partial pressure of the oxygen in the exhaust gas changes abruptly by orders of magnitude causing a step change in the voltage across the electrodes. This voltage change provides the signal to the control logic, which, in turn, transmits a signal to the fuel supply system.

2.2.10.4 Feedback-Control Systems

In addition to the feedback-control systems noted above, an adaptive type feedback-control system has been under development by the Optimizer Control Corporation for several years. Unlike conventional feedback systems which adjust the air/fuel ratio at each engine-operating point in accordance with a predetermined schedule, the Optimizer system uses a small secondary intake manifold and oscillating dither arrangement which continually changes the air-flow rate within a narrow band. The resulting small vehicle accelerations and decelerations are sensed by an accelerometer. The accelerometer output is transmitted to the control logic which continually adjusts air/fuel ratio and/or spark-timing for optimal engine operation.

2.3 REFERENCES

2-1. C. E. Scheffler, "Combustion Chamber Surface Area, A Key To Exhaust Hydrocarbons," SAE Paper No. 660111, SAE Progress in Technology, 12, Vehicle Emissions, Part II, Society of Automotive Engineers, New York (1966) p. 60.

2-2. W.A. Daniel and J.T. Wentworth, "Exhaust Gas Hydrocarbons - Genesis and Exodus," SAE Paper No. 486B, SAE National Automobile Week, SAE Technical Progress Series, 6, Vehicle Emissions, Detroit, Michigan, Society of Automotive Engineers, New York, (March 1962), pp. 192-196.

2-3. M.A. Freeman and R.C. Nicholson, "Valve Timing for Control of Oxides of Nitrogen (NO_x)," SAE Paper No. 720121, SAE Congress, Detroit, Michigan, Society of Automotive Engineers, New York, (January 1972).

2-4. R.M. Siewert, "How Individual Valve Timing Events Affect Exhaust Emissions," SAE Paper No. 710609, SAE Meeting, Montreal, Canada, Society of Automotive Engineers, New York, (June 1971).

2-5. W.U. Roessler, A. Muraszew, and R.D. Kopa, Assessment of the Applicability of Automotive Emission Control Technology to Stationary Engines, Report No. EPA-650/2-74-051, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, (July 1974); prepared by The Aerospace Corporation, El Segundo, California.

2-6. E.F. Obert, Internal Combustion Engines, 3rd Ed., International Textbook Company, Scranton, Pennsylvania (1968).

2-7. M.G. Hinton, et. al., An Assessment of the Effects of Lead Additives in Gasoline on Emission Control Systems Which Might Be Used To Meet the 1975-76 Motor Vehicle Emission Standards, Report No. TOR-0172(2787)-2, The Aerospace Corporation, El Segundo, California, (November 1971).

2-8. J.J. Gumbleton, R.A. Bolton, and H.W. Lang, "Optimizing Engine Parameters with Exhaust Gas Recirculation," SAE Paper No. 740104, Society of Automotive Engineers, New York, (February 1974).

2-9. T. Iura, W.U. Roessler, and H.M. White, Research Plan for Achieving Reduced Automotive Energy Consumption, Report No. ATR-76(7467)-1, The Aerospace Corporation, El Segundo, California (October 1975).

3. ENGINE SELECTION AND COMMON SYSTEMS

3.1 INTRODUCTION

This section of the report identifies the 28 engines selected for examination in this study. This is followed by a brief description of the normalization procedure applied to all fuel economy data considered for the engine/vehicle configurations examined. This procedure accounts for the effects of inertia weight and rear axle ratio variations, permitting a more meaningful assessment of the fuel economy trends observed for the past several model years.

Then, a discussion is presented of crankcase and evaporative emission control technology. In the main, similar crankcase and evaporative emission control systems are used by the various automobile manufacturers, and the effects of these systems on vehicle fuel economy and emissions are negligible.

Finally, vehicle accessories and their power consumption characteristics are briefly discussed.

3.2 ENGINE SELECTION

In the evaluation of the effects of engine control modifications on vehicle performance, fuel economy, and emissions, a total of 28 automobile engines has been selected for detailed examination in this study. These engines fall into four horsepower categories: 35-50 HP, 51-75 HP, 76-100 HP, and 101-150 HP. The emission levels of interest include the 1974 through 1976 California and 49-states standards, as well as pre-1968 (49 states) or pre-1966 (California) configurations.

As shown in Table 3-1, 12 of the selected engines are domestic, whereas the remaining 16 are imported. The domestic engines as well as most imported engines are carbureted using either single- or multi-venturi carburetors. Conversely, five of the imported engines are currently equipped with electronic or mechanical fuel injection, which has been used either since the introduction of these vehicles in the United States or in later years as a replacement for the carburetor.

TABLE 3-1. ENGINE SELECTION

HP Class and Manufacturer	CID	Rated HP[a]	Rated Rpm[a]	Fuel System[b]	Trans-mission	Typical Automobile Models	1975 Emission Control System[c]	% Of 1974 Sales in U. S.	Years on U. S. Market	DOT Engine Test Program	Reasons For Selection
35-50 HP											
VW	96.7	48	4200	FI	M4; A	Beetle; Fastback	FI, EGR	>70	11	Yes	Only engine in class
51-75 HP											
Fiat	78.7	62	6000	2V	M4	128 Series	AIR	>50	>4	No	Italian design
British Leyland	91	54	5000	1V	M4	MG Midget	AIR, EGR	NA	NA	No	English design
Nissan	85	70	6000	2V	M4; A	Datsun B 210	AIR, EGR[c]	30	2	No	Japanese design
Toyota	96.9	75	5800	2V	M4; 5	Corolla; Carina	AIR[c]	38	6	No	Popular engine
VW	89.7	70	5800	2V	M4; A	Dasher; Rabbit	AIR, EGR, CAT	12	3	Yes	Modern design
76-100 HP											
AMC	232	90	3050	1V	M3; A	Gremlin; Hornet; Pacer	AIR, EGR, CAT	>35	>11	Yes	Long history
AMC	258	95	3050	1V	M3; A	Pacer; Hornet; Matador	AIR, EGR, CAT	Increasing	6	Yes	Popular engine
Chrysler	225	100	3600	1V	M3; A	Dart; Duster; Coronet	EM, CAT, EGR	37	>11	Yes	Long history
Ford	140	83	4800	2V	M4; A	Pinto; Capri; Mustang II	EGR, AIR[c]	21	3	Yes	New design
Ford	170.8	97	4400	2V	M3; A	Pinto; Capri; Mustang II	EGR, AIR, CAT	8	3	No	Modern design
Ford	250	86	3200	1V	M3; A	Maverick; Comet; Torino	EGR, AIR, CAT	10	8	Yes	Long history
GM	140	78	4200	1V	M4; A	Vega; Monza	EGR, CAT	11	6	Yes	Small domestic
Audi	97	81	5800	FI	M4; A	Fox	AIR, EGR[c]	50	2	No	Modern, Fuel Injection
Audi	114.5	95	5500	FI	M4; A	100 Series	AIR, EGR[c]	50	5	No	Fuel Injection
BMW	121.3	96	5500	2V	M4; A	2002 Sedan	EM, EGR, TR, AIR	NA	9	No	High performance
British Leyland	110	78.5	5000	1V	NA	MG-B; Austin Marina		50	>9	No	Long history
Nissan	119.1	97	5600	2V	M4; A	Datsun 610, 620, 710	AIR, EGR[c]	52	3	Yes	New design
Peugeot	120	88	5500	2V	M4; A	504 Series	AIR, TR	100	6	No	French design
Toyota	133.6	96	4800	2V	M4; A	Celica; Corona	AIR, EGR[c]	53	2	No	New engine
Volvo	121	98	6000	FI	M5; A	242, 244, 245 Series	AIR, EGR[c]	74	>8	Yes	Swedish design
101-150 HP											
AMC	304	120	3200	2V	M3; A	Gremlin; Hornet; Matador	AIR, EGR, CAT	25	7	No	Popular engine
Chrysler	318	150	4000	2V	M3; A	Dart; Duster; Valiant	EM, EGR, CAT[d]	36	>11	Yes	Long history
Ford	351	148	3800	2V	A	Granada; Torino; LTD	EGR, AIR, CAT[e]	21	8	Yes	Long history
GM	250	105	3800	1V	M3; A	Camaro; Nova; Chevelle	EGR, CAT, EFE	7	10	Yes	Long history
GM	350	145	3800	2V	M3; A	Impala; Monte Carlo	EGR, CAT, EFE	50	9	Yes	Most popular engine
Daimler Benz	167.6	120	4800	4V	A	280 Series	EGR, AIR, CAT	NA	5	No	German design
Saab	121.1	115	5500	FI	M4; A	99 Series	FI, EGR[f]	>80	4	Yes	Modern, Fuel Injection

[a] Discrepancies noted in ratings from different sources

[b] FI = fuel injection
IV = single-venturi carburetor
2V = two-venturi carburetor

[c] AIR = air injection
CAT = catalyst
EFE = early fuel evaporation
EM = engine modification
FI = fuel injection
TR = thermal reactor

[d] Catalysts on models sold in California

[e] Some models without catalyst

[f] Some models without EGR; some models with AIR

Several factors have been considered in the engine selection process, including sales volume over the past several years, number of years in production, use of fuel injection, catalytic and non-catalytic emission control in 1975 and/or 1976, and the use of manual or automatic transmission. At least one engine has been chosen from each foreign country exporting to the United States to provide a means for determining inherent design and operational differences which might exist between domestic and foreign automobile engines.

Currently, the VW Beetle represents the only automobile sold in the United States which falls into the 35-50 HP category. While the basic engine has a long history, the fuel-injected version has been introduced more recently. Several years ago, a number of other imported vehicles in this horsepower category had been available on the United States market, including the Fiat 850, Honda 600, Simca 1000, and Ford Anglia. However, production or sale of these vehicles in the United States has been discontinued by the manufacturers for various reasons.

Five engines have been selected in the 51-75 HP range, representing Italian, English, Japanese, and German designs. None of the domestic manufacturers produces an engine falling into this category. The 76-100 HP category is represented by 15 engines, of which 7 are domestic and 8 are foreign. Most of the engines are carbureted, using single or dual venturis. The 100-150 HP category consists of five domestic and two imported engines. Except for the GM 250-CID engine, the domestic engines selected are sales leaders, in particular, the GM 350-CID engine, which contributed more than 50 percent to the GM 1974 engine production volume.

3.3 NORMALIZATION PROCEDURE

Vehicle fuel economy is impacted by many parameters, including primarily engine efficiency, vehicle inertia weight, rear axle ratio, engine displacement and horsepower output, and transmission type. Other factors contributing to fuel economy are tire size and type, gear ratios, accessory loads, and vehicle aerodynamics. Since the latter factors are either unknown or have remained nearly constant for the vehicles and model years considered in this study, they have been eliminated from further consideration in this part of the study. While the use of air conditioning results in a moderate reduction in fuel economy, as discussed in Section 3.5, the fuel economy data of the certification vehicles tested without and with air conditioning show no clear trends.

For a meaningful comparison of vehicle fuel economy as affected by engine design and component calibration modifications, the fuel economy data for each engine/vehicle/transmission configuration have been normalized to a common inertia weight and rear axle ratio. The normalization method is based on inertia weight and rear axle ratio sensitivity coefficients derived from simulation data presented by Malliaris, et al. (Ref. 3-1), and by Gould (Ref. 3-2). In this context, the sensitivity coefficients are defined as the ratio of the percent change in fuel economy to the percent change in inertia weight or rear axle ratio for constant engine size and transmission type. The sensitivity coefficients used in this study are listed in Table 3-2 for the city and highway driving cycles and for two rear axle ratio categories. While the available data (Refs. 3-1 through 3-6) show moderate differences in the sensitivity coefficients for different model years and engine/vehicle configurations, the observed variations and conflicting trends do not warrant the use of multiple sets of sensitivity coefficients at this time.

The fuel economy and emission data reported by the EPA for 1973 and 1974 model year vehicles are based on the 1972 cold start Federal Test Procedure (FTP). Conversely, all 1975 and 1976 data are based on the 1975 FTP, in which the cold start effects are mitigated by means of cold start/hot start averaging. As a result, the fuel economy and NO_x emissions determined in accordance with the 1975 FTP are higher than for the 1972 FTP, while the HC and CO emissions are lower, as shown in Table 3-3. To provide a common basis for comparison, the adjusted 1973 and 1974 model year data are then normalized following the previously described procedure.

TABLE 3-2. FUEL ECONOMY SENSITIVITY COEFFICIENTS

Sensitivity Coefficient	Rear Axle Ratio/Driving Cycle			
	2.5 to 3.5		3.5 to 4.5	
	City	Highway	City	Highway
Inertia Weight	-0.32	-0.20	-0.32	-0.20
Rear Axle Ratio	-0.31	-0.52	-0.45	-0.72

TABLE 3-3. FUEL ECONOMY AND EMISSION CONVERSION FACTOR: 1972 VERSUS 1975 FTP

Conversion Factor			
Fuel Economy[a]	Emissions[b]		
mpg_{75}/mpg_{72}	HC_{75}/HC_{72}	CO_{75}/CO_{72}	NO_{x75}/NO_{x72}
1.05	0.89	0.72	1.03

[a] Ref. 3-7.

[b] Ref. 3-8.

3.4 COMMON SYSTEMS

In principle, the emissions from internal combustion engines originate from three sources: (a) the crankcase, (b) the fuel-supply system, and (c) the engine exhaust. Both the crankcase and evaporative emission control systems described in the following subsections are relatively simple in design, showing only minor differences between the various manufacturers. Complete control of crankcase emissions has been achieved by means of closed-loop crankcase ventilation systems, while the evaporative emissions from the fuel tank and carburetor have been reduced in recent years to levels significantly below the standard. Conversely, the exhaust emissions which are directly related to the combustion process are strongly affected by many parameters, including air/fuel ratio, spark timing, EGR, and engine speed and load. The effects of these parameters on vehicle/fuel economy and emissions are discussed in Sections 4 and 5.

3.4.1 Crankcase Emission Control System

All 1968 and later model year automobile engines marketed in the United States are equipped with closed-loop positive crankcase ventilation (PCV) systems, replacing the open-loop systems used by most manufacturers between 1961 and 1967 and the draft tube system used in earlier model years. The functional characteristics of these three basic systems are briefly described in the following paragraphs.

Before model year 1961, a draft tube crankcase ventilation system was used which was designed to draw air through the oil filler cap into the crankcase where mixing takes place between the inducted air and the blowby gases. The air/vapor mixture then discharges to the atmosphere through the road draft tube arrangement.

In the early 1960's, the draft tube system was replaced by an open-type (PCV) system consisting of an open engine breather cap, a PCV valve, and a hose connection between the PCV valve and the intake manifold. The PCV valve is designed to modulate the crankcase ventilation flow rate in accordance with engine air flow to minimize driveability problems caused by excessive leaning of the air/fuel mixture provided by the carburetor. While the system is very effective in controlling crankcase emissions under light-load operating conditions, it has undesirable performance characteristics in the high-load regime. In this case, the manifold pressure decreases while crankcase pressure increases, which forces part of the crankcase vapors back through the filler cap and out into the atmosphere.

The closed PCV system, used exclusively since 1968, is designed to provide complete control of crankcase emissions. As illustrated in Figure 3-1, this system is a simple modification of the open system, using a sealed oil filler cap in place of the open breather cap.

Under normal engine operation, the closed system operates like the open system, drawing air from the upstream side of the air filter into the crankcase and back out through the PCV valve. Conversely, at high loads, some of the crankcase fumes escape through the air hose into the air cleaner where mixing takes place with the engine intake air.

In well-maintained engines, PCV has no measurable effect on vehicle performance, fuel economy, and driveability.

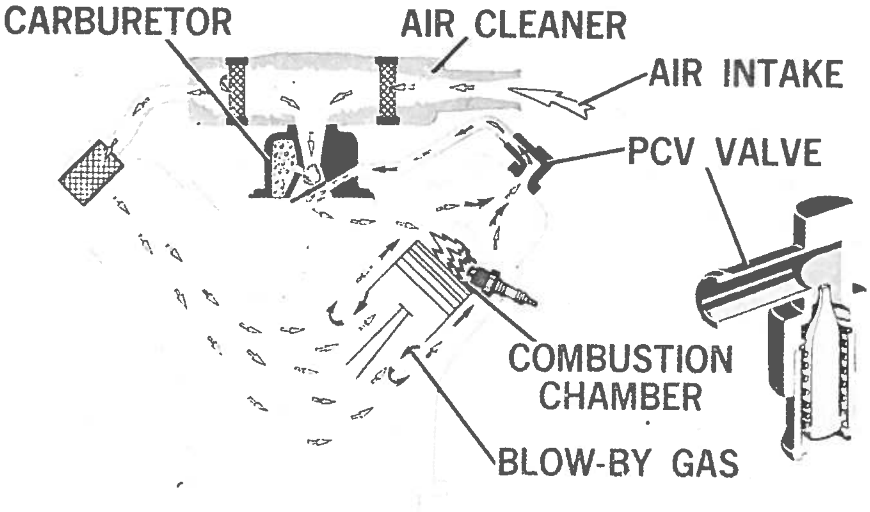


FIGURE 3-1. CLOSED-LOOP POSITIVE CRANKCASE VENTILATION SYSTEM

3.4.2 Evaporative Emission Control System

The promulgation of evaporative emission regulations in 1970 in California and in 1971 nationwide has forced the use of evaporative emission control systems in all automobiles marketed in the United States. A typical evaporative emission control system, exemplified by the Chrysler design, is shown in Figure 3-2. In its present form, the system consists of a domed fuel tank, a liquid/vapor separator, a sealed fuel tank filler cap with pressure/vacuum relief valve, a fuel tank vent line, an overfill limiter, a charcoal canister, a carburetor bowl vent line on some models, and a purge line. In alternate designs, the crankcase is used as vapor storage volume in place of the charcoal canister.

When the fuel tank is filled to the base of the filler tube, fuel vapors become trapped in the domed portion of the tank. Since the vapor flow through the vent line is blocked by the overfill-limiting valve, no additional fuel can enter the tank. Under normal operating conditions, the filler cap operates as a check valve, permitting air to enter the tank as

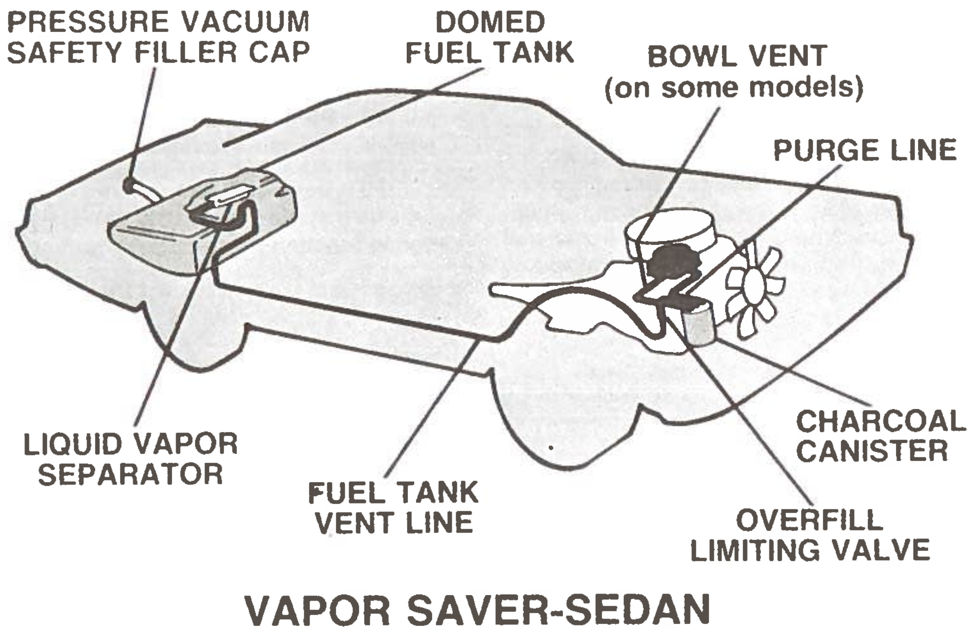


FIGURE 3-2. EVAPORATIVE EMISSION CONTROL SYSTEM

gasoline is used, while preventing fuel vapors from escaping through the cap. The pressure relief valve function of the cap has been added more recently as a safety feature, preventing the buildup of excessively high pressures in the fuel tank caused by system component malfunction or extreme temperature conditions. As tank pressure rises above about 0.5 psi, the limiting valve opens, allowing fuel vapors to flow forward to the engine compartment-mounted charcoal canister. The fuel vapors are temporarily stored in the canister until the unit is purged when the engine is running.

In general, the effectiveness of evaporative emission control systems is more than adequate to meet current emission regulations. With few exceptions, the evaporative HC emissions of the 1976 model certification vehicles are below 1 g/test as compared to the 2 g/test permitted by current regulations. The effect of evaporative emission control on vehicle fuel economy is negligible because of the relatively small amounts of fuel vapor handled by the system.

3.5 ACCESSORIES

The vehicle accessories include essential components, such as the water pump, alternator, and cooling fan, which are essential to operate the vehicle, and the optional accessories, such as power steering, power brakes, and air conditioning (A/C). In general, these accessories are belt-driven directly off the engine. As shown in Figures 3-3 and 3-4, the accessory loads vary markedly with engine speed. The combined horsepower requirement of the accessories, excluding A/C, is about 5 HP at 2000 rpm and 10 HP at 3000 rpm for standard-size cars (Ref. 3-8).

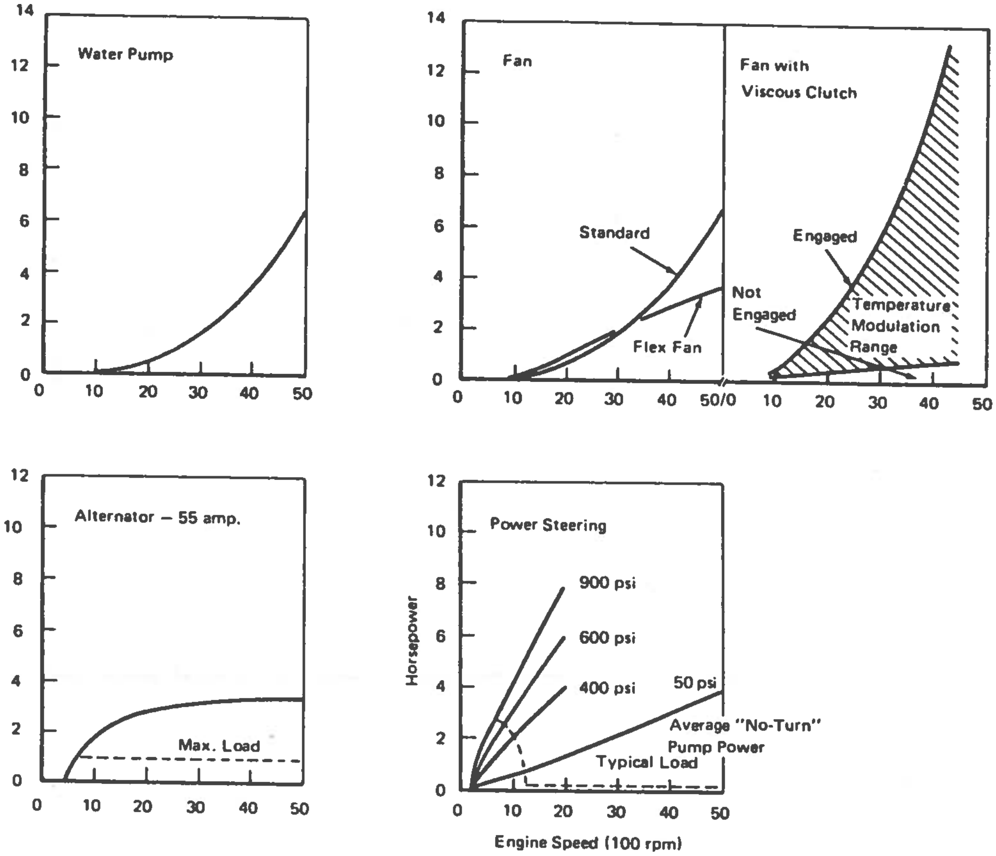


FIGURE 3-3. POWER REQUIREMENTS FOR ACCESSORIES IN STANDARD SIZE AUTOMOBILE (Ref. 3-8)

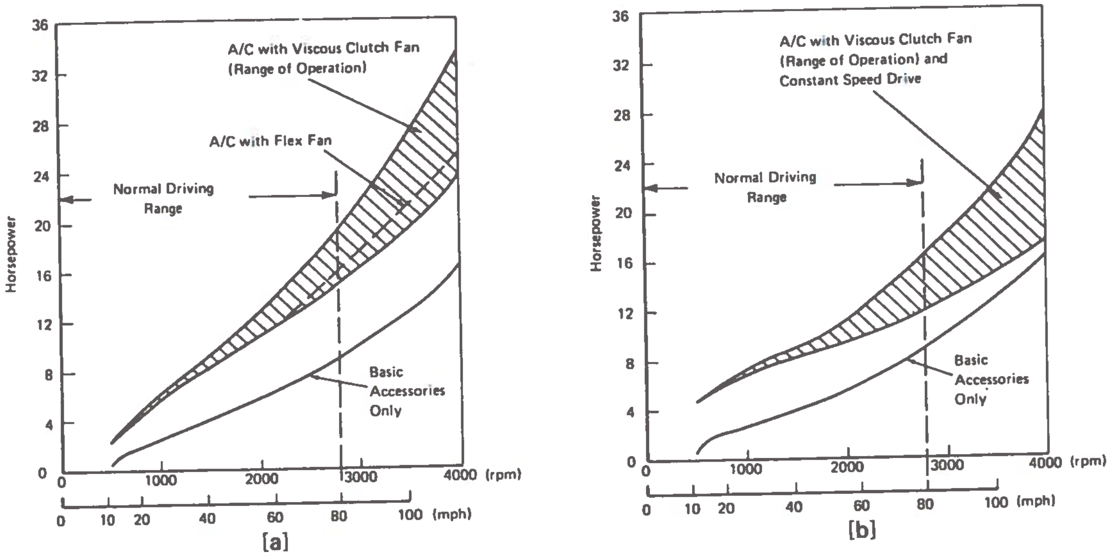


FIGURE 3-4. TOTAL ACCESSORY POWER REQUIREMENTS OF STANDARD SIZE AUTOMOBILE WITH BASIC ACCESSORIES (WATER PUMP, ALTERNATOR, AIR PUMP, POWER STEERING PUMP, STANDARD FAN): (A) A/C WITHOUT CONSTANT-SPEED DRIVE, AND (B) A/C WITH CONSTANT-SPEED DRIVE (Ref. 3-8)

The power requirements of a typical production A/C system with a temperature-modulated viscous clutch fan are quite high, varying between about 3 to 4 HP at engine idle, to about 16 to 20 HP at 3000 rpm if the A/C system is driven at a fixed speed ratio directly off the engine. For highway driving, the A/C load is 20 to 25 percent of the power required to run the vehicle exclusive of the A/C. The corresponding fuel economy decrease is less, 12 to 15 percent, because the engine brake specific fuel consumption (BSFC) is lower at the higher engine loads when the A/C is operating.

A/C loads can be reduced using a constant speed drive for the A/C compressor, so that it absorbs about 4 HP independent of engine speed. The effect of this approach on total accessory loads at various engine rpm is shown in Figure 3-4(b). There is a decrease in power consumption at higher engine speeds, at the expense of a slight increase at low speeds. A two-speed A/C drive is under development by one automobile manufacturer (Ref. 3-8), and other more exotic concepts have been suggested to reduce A/C power requirements.

While the use of A/C has undoubtedly a negative impact on vehicle fuel economy, the certification vehicle data do not always follow this trend. Several reasons may be cited for the observed discrepancy, including the small data sample generally available from the certification program, as well as normal test-to-test and hardware-to-hardware variations.

3.6 REFERENCES

3-1. A. C. Malliaris, E. Withjack, and H. Gould, "Simulated Sensitivities of Auto Fuel Economy, Performance and Emissions," SAE Paper No. 760157, Society of Automotive Engineers, New York (February 23-27, 1976).

3-2. Personal communication with H. Gould, Transportation Systems Center, Department of Transportation, Cambridge, Mass.

3-3. A. C. Malliaris, H. Hsia, and H. Gould, "Concise Descriptions of Auto Fuel Economy and Performance in Recent Model Years," SAE Paper No. 760045, Society of Automotive Engineers, New York (February 23-27, 1976).

3-4. J. D. Murrell, "Factors Affecting Automotive Fuel Economy," SAE Paper No. 750958, Society of Automotive Engineers, New York (October 13-17, 1975).

3-5. T. C. Austin and K. H. Hellman, "Passenger Car Fuel Economy Trends and Influencing Factors," SAE Paper No. 730790, Society of Automotive Engineers, New York (September 1973).

3-6. G. J. Huebner, Jr., and D. J. Gasser, "General Factors Affecting Vehicle Fuel Consumption," SAE Paper No. 730518, Society of Automotive Engineers, New York (May 1973).

3-7. T. C. Austin, R. B. Michael, G. R. Service, "Passenger Car Fuel Economy Trends Through 1976," SAE Paper 750957, Society of Automotive Engineers, New York (October 13-17, 1975).

3-8. T. A. Huls, "Evolution of Federal Light-Duty Mass Emission Regulations," SAE Paper No. 730554, Society of Automotive Engineers, New York (May 14-18, 1973).

3-9. D. A. Hurter, et al, <u>A Study of Technological Improvements in Automobile Fuel Consumption,</u> Report No. DOT-TSC-OST-74-40, Department of Transportation, Washington, D. C. (December, 1974); prepared by A. D. Little, Inc., Cambridge, Massachusetts.

4. STATUS OF DOMESTIC AUTOMOBILE ENGINE CONTROL PRACTICES

This section of the report describes the control systems and techniques used by domestic automobile manufacturers to meet current and past emission regulations and examines the effects of engine subsystem calibration modifications implemented during the past several years on the fuel economy and emission characteristics of the selected engine/vehicle configurations.

4.1 AMERICAN MOTORS CORPORATION

4.1.1 Engine/Vehicle Configurations

Three engines consisting of two in-line 6-cylinder models and a 90-degree V-8 have been chosen to illustrate AMC automotive engine control practices over the past 9 years. One of these engines, a 232-CID 6-cylinder unit, offers chronological engine family continuity from prior to initiation of Federal automotive emission standards in 1968 through 1976. The other two engines, more recent additions to the AMC line, are a 258-CID 6-cylinder engine introduced in 1972 and a 304-CID V-8 introduced in 1970.

Typical engine/vehicle combinations team the 232-CID 6-cylinder engine as a standard offering with the AMC Gremlin or Pacer in the 3000-pound inertia weight class and the Hornet or Pacer in the 3500-pound class. Either of the larger engines are offered as an option in the Gremlin and Hornet line. Three-speed automatic and manual transmissions are available in the Gremlin and Hornet, and an overdrive unit is available with manual transmission 6-cylinder models.

The 258-CID engine is standard in the Matador series, which has models in both the 4000- and 4500-pound inertia weight class. Again the 304-CID V-8 is an option, and either manual or automatic three-speed transmissions are available depending on specific engine/body series combinations.

4.1.2 Engine Design Features

In order to aid a detailed discussion of changes in AMC's engine control practices and systems over past years and to provide an overview of each engine, Tables 4-1 through 4-3 present key engine design parameters for each engine of interest (Refs. 4-1 through 4-13). The years for which data are shown are chosen as representative of a complete description of the progression of recent automotive engine control practices.

Because of the great similarity between the two 6-cylinder engines, the discussion of their engine control systems is combined in Section 4.1.3.

4.1.3 AMC 232- and 258-CID Engines

4.1.3.1 Engine Modifications

Current practice on the AMC 232- and 258-CID engines is aimed at reducing the formation of pollutants during the combustion process. "Low-quench" wedge-type cylinder heads using a relatively small surface-to-volume ratio (Tables 4-1 and 4-2) are employed to impede the formation of CO and promote the oxidation of HC by minimizing the quenching process which occurs at the boundary between the combustion chamber and the working gas and in overly lean air/fuel mixture pockets. Compression ratios lowered from previous years aid the control of NO_x by lowering peak combustion temperatures.

With the advent of increasingly sophisticated EGR systems, extreme intake-exhaust valve overlap to obtain charge dilution has decreased as a means of controlling the formation of NO_x. As shown in Tables 4-1 and 4-2, valve overlap was highest in the 1974 model year engines without EGR and lower both for earlier models, not requiring NO_x control, and for 1975/1976 models which employ more effective EGR systems.

One 1976 engine still using a relatively high degree of valve overlap is the two-venturi, 258-CID engine. As shown in Table 4-2, the subject engine does not use an oxidizing catalyst and employs approximately 2.5 deg. more intake valve opening advance than the 1976 single-venturi versions of the same engine. In addition, nearly 4 deg. of additional exhaust valve closing delay relative to the 1976 single-venturi engine are used to achieve increased valve overlap.

The additional intake valve opening advance is significant when correlated with the fact that a catalytic converter is not used. Typically,

TABLE 4-1. ENGINE SPECIFICATIONS: AMC 232-CID ENGINE

Engine Parameter	Model Year									
	1976		1975		1974		1970		1967 and 1968	
	49 States	California	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	6		6		6		6		6	
Bore, in.	3.75		3.75		3.75		3.75		3.75	
Stroke, in.	3.50		3.50		3.50		3.50		3.50	
Displacement, cu in.	232		232		232		232		232	
Surface/Volume, 1/in.	5.8		5.8		5.8		5.8		-	
Compression Ratio	8.0		8.0		8.0		8.5		8.5	
Cylinder Head Type	OHV		OHV		OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	100 at 3600		100 at 3600		100 at 3600		145 at 4300 (1V) 155 at 4400 (2V)		145 at 4300 (1V) 155 at 4400 (2V)	
Torque, ft-lb, at Engine Speed, rpm	185 at 1800		185 at 1800		185 at 1800		215 at 1600 (1V) 222 at 1600 (2V)		215 at 1600 (1V) 222 at 1600 (2V)	
Exhaust System Type	Single		Single		Single		Single		Single	
Combustion Chamber Configuration	Wedge		Wedge		Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.787		1.787		1.787		1.787		-	
Intake Valve Lift, in.	0.372		0.372		0.372		-		-	
Exhaust Valve Diameter, in.	1.406		1.406		1.406		1.406		-	
Exhaust Valve Lift, in.	0.372		0.372		0.372		-		-	
Intake Valve Opens, deg BTC	12.12		12.12		12.5		12.5		-	
Intake Valve Closes, deg ABC	64.80		64.80		66.5		51.5		-	
Intake Valve Duration, deg	256.92		256.92		259.0		244		-	
Exhaust Valve Opens, deg BBC	53.12		53.12		53.5		52.5		-	
Exhaust Valve Closes, deg ATC	23.80		23.80		25.5 with EGR 55.5 w/o EGR		10.5		-	
Exhaust Valve Duration, deg	256.92		256.92		259 with EGR 289 w/o EGR		244			
Valve Overlap, deg	35.92		35.92		38 with EGR 68 w/o EGR		23			
Distributor Type	Breakerless; centrifugal & vacuum adv.		Breakerless; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.	
Basic Ignition Advance, deg BTC at Engine Speed, rpm	8 at 500		5 at 700		5 at 700		3 at 700		5 at 500 (reg. fuel) 8 at 500 (prem. fuel)	
Idle Speed, rpm[a]	550 (A) 850 (M)	700 (A) 850 (M)	550 (A) 600 (M)	700 (A) 600 (M)	600(A) no EGR 550 (A) EGR 700(M) no EGR 600 (M) EGR	700 (A) 600 (M)	550 (A) 600 (M)		600 (A) 600 (M)	
Fast Idle Speed, rpm	1600		1600		1600		2300 (1V) 2000 (2V)		1600 (1V) 1900 (2V)	
Intake Air Temperature Control	Thermostatic		Thermostatic		Ambient		Ambient		Ambient	
Fuel System Type	1-V downdraft carburetor		1-V downdraft carburetor		1-V downdraft carburetor		1-V or 2-V downdraft carburetor		1-V or 2-V downdraft carburetor	
Fuel Metering Method	Fixed orifice with metering rod		Fixed orifice with metering rod		Fixed orifice with metering rod		Fixed orifice with metering rod		Fixed orifice with metering rod	
Enrichment Method	Stepped rod; mechanical and vacuum actuated		Stepped rod; mechanical and vacuum actuated		Stepped rod; mechanical and vacuum actuated		Stepped rod; mechanical and vacuum actuated		Stepped rod; mechanical and vacuum actuated	
Choke Type	Automatic		Automatic		Automatic		Automatic		Automatic	
Carburetor Venturi Diameter, in.	1.31		1.31		1.31		1.31 (1V) 1.1875 (2V)		1.375 (1V) 1.1875 (2V)	
Carburetor Maximum Air Flow, cfm, at Vacuum, in. Hg	200 cfm at 3 in. Hg		200 cfm at 3 in. Hg		185 cfm at 3 in. Hg		-		-	
Emission Control Systems	AIR[b] EGR[b, c] EVAP[b, c] PCV[b, c]	AIR[b, c] CAT[b, c] EGR[b, c] EVAP[b, c] PCV[b, c] TCS[b, c]	AIR[d, e] CAT[e] EGR[c, d, e] EVAP[c, d, e] PCV[c, d, e]	AIR[b, c] CAT[b, c] EGR[b, c] EVAP[b, c] PCV[b, c] TCS[b, c]	AIR[e, f] EGR[g] EM EVAP PCV TCS	EGR EM EVAP PCV TCS	EM PCV	EM EVAP PCV	PCV	EM PCV
Emission Control Devices	BPS[b, c] EGR CTO b, c Spark CTO[h]	BPS[b, c] EGR CTO b, c Spark CTO b, c	EGR CTO c, d, e Spark CTO c, d, e	BPS[b, c] EGR CTO b, c Spark CTO b, c	EGR CTO SparkCTO	BPS EGR CTO Spark CTO	Deceleration control valve			

[a] A = automatic transmission; M = manual transmission

[b] Hornet and Pacer, manual transmission

[c] Gremlin, automatic and manual transmission; Hornet and Pacer, automatic transmission

[d] Hornet, manual transmission; Matador, automatic transmission

[e] Matador, manual transmission

[f] Matador, automatic transmission

[g] Hornet and Javelin, automatic and manual transmission; Matador, manual transmission

[h] Gremlin, manual transmission

TABLE 4-2. ENGINE SPECIFICATIONS: AMC 258-CID ENGINE

Engine Parameter	Model Year							
	1976		1975		1974		1972	
	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	6		6		6		6	
Bore, in.	3.75		3.75		3.75		3.75	
Stroke, in.	3.90		3.90		3.90		3.90	
Displacement, cu in.	258		258		258		258	
Surface/Volume, 1/in.	5.33		5.33		5.33		5.33	
Compression Ratio	8.0		8.0		8.0		8.0	
Cylinder Head Type	OHV		OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	110 at 3500 (1V) 120 at 3600 (2V)		110 at 3500		110 at 3500		150 at 4000	
Torque, ft-lb, at Engine Speed, rpm	195 at 2000 (1V) 200 at 2000 (2V)		195 at 2000		195 at 2000		240 at 1800	
Exhaust System Type	Single		Single		Single		Single	
Combustion Chamber Configuration	Wedge		Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.787		1.787		1.787		1.787	
Intake Valve Lift, in.	0.372 (1V) 0.4 (2V)	0.372 (1V) 0.4 (2V)	0.372		0.372		0.372	
Exhaust Valve Diameter, in.	1.406		1.406		1.406		1.406	
Exhaust Valve Lift, in.	0.372 (1V) 0.4 (2V)	0.372 (1V) 0.4 (2V)	0.372		0.372		0.372	
Intake Valve Opens, deg BTC	12.12 (1V) 14.58 (2V)	12.12 (1V) 14.58 (2V)	12.12		12.5		12.12	
Intake Valve Closes, deg ABC	64.8 (1V) 68.79 (2V)	64.8 (1V) 68.79 (2V)	64.8		66.5		64.8	
Intake Valve Duration, deg	256.92 (1V) 263.37 (2V)	256.92 (1V) 263.37 (2V)	256.92		259.0		256.92	
Exhaust Valve Opens, deg BBC	53.12 (1V) 55.59 (2V)	53.12 (1V) 55.59 (2V)	53.12		53.5		53.12	
Exhaust Valve Closes, deg ATC	23.80 (1V) 27.78 (2V)	23.80 (1V) 27.78 (2V)	23.8		25.5 with EGR 55.5 w/o EGR		23.8	52.0
Exhaust Valve Duration, deg	256.92 (1V) 263.37 (2V)	256.92 (1V) 263.37 (2V)	256.92		259 with EGR 289 w/o EGR		256.92	285.10
Valve Overlap, deg	35.92 (1V) 42.36 (2V)	35.92 (1V) 42.36 (2V)	35.92		38 with EGR 68 w/o EGR		35.92	64.12
Distributor Type	Breakerless; centrifugal and vacuum advance		Breakerless; centrifugal and vacuum advance		Breaker point; centrifugal and vacuum advance		Breaker point; centrifugal and vacuum advance	
Basic Ignition Advance, deg BTC,[a] at Engine Speed, rpm	8 at 500 (A) 6 at 500 (M)		3 at 700		3 at 700		3 at 500	
Idle Speed, rpm[a]	700 (A) 850 (M)		550 (A) 600 (M)	700 (A) 600 (M)	600 (A), no EGR 550 (A), EGR 700 (M), no EGR 600 (M), EGR	700 (A) 600 (M)	550 (A) 600 (M)	600 (A) 700 (M)
Fast Idle Speed, rpm	1600 (1V) - (2V)		1600		1600		1600	
Intake Air Temperature Control	Thermostatic 1V or 2V downdraft carburetor		Thermostatic 1V downdraft carburetor		Thermostatic 1V downdraft carburetor		Thermostatic 1V downdraft carburetor	
Fuel Metering Method	Fixed orifice with stepped rod		Fixed orifice with stepped rod		Fixed orifice with stepped rod		Fixed orifice with stepped rod	
Enrichment Method	Stepped rod; mechanical and vacuum actuated		Stepped rod; mechanical and vacuum actuated		Stepped rod; mechanical and vacuum actuated		Stepped rod; mechanical and vacuum actuated	
Choke Type	Automatic		Automatic		Automatic		Automatic	
Carburetor Venturi Diameter, in.	1.31 (1V) 1.125 (2V)		1.31		1.31		1.31	
Carburetor Maximum Air Flow, cfm, at Intake Vacuum, in. Hg	200 at 3 330 at 2		200 at 3		185 at 3		185 at 3	
Emission Control Systems	AIR[c, d] CAT[d] EGR[c, d, e] EVAP[c, d, e] PCV[c, d, e]	AIR CAT EGR EVAP PCV TCS	AIR[c, d] CAT[d] EGR[c, d, e] EVAP[c, d, e] PCV[c, d, e]	AIR CAT EGR EVAP PCV TCS	AIR[f] EGR[f, g] EM EVAP PCV TCS	AIR EGR EM EVAP PCV TCS	EM EVAP PCV	EM EVAP PCV, TCS[i]
Emission Control Devices	BPS[c, d, e,] EGR CTO c, d, e, Spark CTO[j]	BPS EGR CTO Spark CTO	EGR CTO c, d, e Spark CTO c, d, e	BPS EGR CTO Spark CTO	EGR CTO Spark CTO	BPS EGR CTO Spark CTO	–	–

[a] A = automatic transmission; M = manual transmission

[b] Gremlin and Hornet, automatic and manual transmissions; Matador, manual transmission

[c] Matador, automatic transmission; Hornet and Pacer, manual transmission

[d] Matador, manual transmission

[e] Gremlin, automatic and manual transmission; Hornet and Pacer, automatic transmission

[f] Matador, automatic and manual transmissions

[g] Hornet and Javelin, automatic and manual transmissions

[h] Matador, automatic transmission

[i] Gremlin, Hornet, and Matador, automatic and manual transmissions; Javelin, automatic transmission

[j] 2V carburetor Pacer only

TABLE 4-3. ENGINE SPECIFICATIONS: AMC 304-CID ENGINE

Engine Parameter	Model Year									
	1976		1975		1974		1972		1970	
	49 States	California	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	8		8		8		8		-	
Bore, in.	3.75		3.75		3.75		3.75		-	
Stroke, in.	3.44		3.44		3.44		3.44		-	
Displacement, cu in.	304		304		304		304		-	
Surface/Volume, 1/in.	6.6		6.6		6.6		6.6		-	
Compression Ratio	8.4		8.4		8.4		8.4		9.0	
Cylinder Head Type	OHV		OHV		OHV		OHV		-	
Advertised HP at Engine Speed, rpm	150 at 4200		150 at 4200		150 at 4200		210[a] at 4400		-	
Torque, ft-lb, at Engine Speed, rpm	245 at 2500		245 at 2500		245 at 2500		300 at 2600		-	
Exhaust System Type	Single		Single		Single		Single		-	
Combustion Chamber Configuration	Wedge		Wedge		Wedge		Wedge		-	
Intake Valve Diameter, in.	1.787		1.787		1.787		1.787		-	
Intake Valve Lift, in.	0.426		0.426		0.426		0.426		-	
Exhaust Valve Diameter, in.	1.406		1.406		1.406		1.406		-	
Exhaust Valve Lift, in.	0.426		0.426		0.426		0.426		-	
Intake Valve Opens, deg BTC	14.75		14.75		14.75		14.75		-	
Intake Valve Closes, deg ABC	68.75		68.75		68.75		68.75		-	
Intake Valve Duration, deg	263.5		263.5		263.5		263.5		-	
Exhaust Valve Opens, deg BBC	56.75		56.75		56.75		56.75		-	
Exhaust Valve Closes, deg ATC	26.75		26.75		26.75		26.75	56.75	-	
Exhaust Valve Duration, deg	263.5		263.5		263.5		263.5	293.5	-	
Valve Overlap, deg	41.5		41.5		41.5		41.5	71.5	-	
Distributor Type	Breakerless; centrifugal & vacuum adv.		Breakerless; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.		-	
Basic Ignition Advance, deg BTC at Engine Speed, rpm[b]	10 at 500 (A) 5 at 500 (M)	5 at 500 (A) 5 at 500 (M)	5 at 700		5 at 700		5 at 500		-	
Idle Speed, rpm[b]	700 (A) 750 (M)		700 (A) 750 (M)		700 (A) 750 (M)		650 (A) 750 (M)	700 (A) 750 (M)	-	
Fast Idle Speed, rpm	1600		1600		1600		1600		-	
Intake Air Temperature Control	Thermostatic		Thermostatic		Thermostatic		Thermostatic		-	
Fuel System Type	2-V downdraft carburetor		2-V downdraft carburetor		2-V downdraft carburetor		2-V downdraft carburetor		-	
Fuel Metering Method	Fixed orifice		Fixed orifice		Fixed orifice		Fixed orifice		-	
Enrichment Method	Power valve		Power valve		Power valve		Power valve		-	
Choke Type	Automatic		Automatic		Automatic		Automatic		-	
Carburetor Venturi Diameter, in.	1.080		1.080		1.080		1.080		-	
Carburetor Maximum Air Flow, cfm, at Vacuum, in. Hg	290 at 3		290 at 3		290 at 3		290 at 3		-	
Emission Control Systems	AIR CAT[c] EGR EVAP PCV	AIR CAT[d] EGR EVAP PCV TCS	AIR CAT[c] EGR EVAP PCV	AIR CAT[d] EGR EVAP PCV TCS	AIR[e] EGR EM EVAP PCV TCS	AIR EGR EM EVAP PCV TCS	EM EVAP PCV TCS[f]	EM EVAP PCV TCS[f, g]		
Emission Control Devices	BPS EGR CTO	BPS EGR CTO Spark CTO	EGR CTO Spark CTO	BPS EGR CTO Spark CTO	EGR CTO Spark CTO	BPS EGR CTO Spark CTO	Spark CTO f, h	Spark CTO f, g, h		

[a] Gross rating

[b] A = automatic transmission; M = manual transmission

[c] Single catalytic converter

[d] Dual catalytic converter

[e] Ambassador and Matador, automatic transmission

[f] All automatic transmission vehicles

[g] Gremlin and Javelin, manual transmission

[h] Spark CTO is used on some models that do not use TCS

use of intake and exhaust valve opening advance to achieve emission control is primarily indicative of HC abatement. Conversely, little or no additional intake valve opening advance and a substantial amount of exhaust valve closing delay are usually associated with an emphasis on NO_x control (Ref. 4-14). Thus, in this case, the additional valve overlap of the 1976 two-venturi 258-CID engine is, more likely, for control of HC rather than NO_x. This rationale is supported by the fact that a catalyst is not used with the subject engine, while EGR modulated by exhaust gas backpressure is used for NO_x control. A description of the EGR system is presented in Section 4.1.3.5.

For individual intake and exhaust valve timing in years prior to 1976, little change is noted in the point at which the intake valve opens; however, a marked change toward delayed exhaust valve closing is apparent for later years. As mentioned, this indicates valve timing that is driven primarily by NO_x rather than HC abatement.

It is interesting to note that examination of EPA application certificates reveals that an optional engine configuration was considered for 1975. The optional configuration did not employ EGR but instead used extreme intake-exhaust valve overlap identical to the 1974 non-EGR configuration. However, perusal of the 1975 model year service manuals indicates that this option did not reach production. Whether the reason was an inability to meet 1975 standards or a decision based on a tradeoff of improved vehicle performance versus cost of the EGR system is unknown. Whatever the reason, the 1975 model year configurations indicate that a recovery of the volumetric efficiency at low engine speed, coupled with improved driveability, has been achieved by partially restoring valve timing to the levels used in years prior to emission control.

In the early exhaust emission control years, starting in 1966 for California vehicles and in 1968 for the 49-states vehicles, combustion chamber emission control changes on the 232-CID engine were limited to the replacement of the steel cylinder head gasket with a thicker composition gasket. Coupled with ignition timing retarded only at idle, this lowered combustion pressures, causing lower peak and higher mean combustion temperatures. The resultant higher exhaust temperature lead to continuing oxidation of the unburned HC in the exhaust system and lower HC emissions.

4.1.3.2 Intake System

Thermostatic control of air entering the intake system is a feature of the 1974 and 1975 model year 232- and 258-CID engines, which does not appear on the 1968 and 1970 models. This system consists of an exhaust manifold mounted heat shroud, a hot air hose, and a thermostatically controlled spring-actuated air control valve located in the snorkel of the air cleaner. During engine warmup, when air entering the air cleaner is below 105°F, all inlet air is drawn from the shroud at the exhaust manifold. When sensed air reaches 130°F, the air control valve causes inlet air to be drawn entirely from the engine compartment, while between these temperature operating limits mixes of air from the two sources are provided to the engine. The purpose of the system is to enhance fuel vaporization during engine warmup and thereby decrease HC and CO emissions through improved air/fuel mixture homogeneity and distribution.

All model year 232- and 258-CID engines shown in Tables 4-1 and 4-2 incorporate a thermostatically controlled heat riser valve in the exhaust manifold to direct exhaust heat to the floor of the intake manifold for rapid fuel vaporization during warmup. Starting with the 1974 model year, the AMC 6-cylinder engines incorporate a stainless steel "hot spot" in the intake manifold directly under the carburetor, which provides much faster heat transfer to the incoming air/fuel mixture than older cast iron configurations. This system works in conjunction with the thermostatically controlled air cleaner to reduce HC and CO.

4.1.3.3 Carburetor

4.1.3.3.1 Design Features

Two basic downdraft carburetor types have been used with the 232- and 258-CID engines over the model years listed in Tables 4-1 and 4-2. A dual-venturi unit was available in 1968 and 1970, while a single-venturi carburetor has been the standard for the 1974 through 1976 model years. As noted in Table 4-2 a two-venturi unit was added to the 258-CID engine line in 1976.

Both types of carburetors use five conventional fuel circuits: the float or fuel inlet circuit, the idle or low speed circuit, the main metering or high speed circuit, the pump circuit, and the choke circuit. The float circuits of the subject carburetors are of a conventional design and are not discussed except to note that float levels must be properly set to implement the desired carburetor calibration schedules. The idle circuits are flow limited by idle mixture limiter caps for all model years of interest. A throttle stop solenoid is used on 1974 through 1976 California vehicles with automatic transmissions, while manual models use a dashpot. Hot idle compensation is not used on any of the carburetors available on the 232- and 258-CID engines.

The position of a stepped metering rod in a fixed orifice regulates the amount of fuel admitted to the main discharge nozzle. Metering rod position depends on both mechanical linkage and intake manifold vacuum, with enrichment increasing as the metering rod is withdrawn from the metering jet. Main venturi's are partitioned by multiple concentric sections to form boost venturi's and give more precise control of air/fuel ratio over the total range of operation. An accelerator pump provides additional fuel for smooth performance during low-speed vehicle accelerations. Richer mixtures required for quick cold engine starts and proper warmup performance are provided by a conventional thermostatic choke implemented with a coiled bimetallic spring. Electric assist is not used.

4.1.3.3.2 Carburetor Calibration

As seen in Tables 4-4 and 4-5, both the California and 49-states 1975 and 1976 model year vehicles exhibit slightly richer carburetor settings than their 1974 counterparts. These richer settings are needed, in conjunction with other system modifications, to meet the more stringent 1975/76 emission standards.

4.1.3.4 Ignition System

4.1.3.4.1 Design Features

In 1975, AMC introduced a breakerless ignition system which replaced the conventional breaker point unit used in previous model years. The new system is a breakerless induction discharge (BID) system consisting of an electronic ignition control unit, an ignition coil, a distributor, high-tension wires, and spark plugs.

TABLE 4-4. CERTIFICATION CALIBRATION DATA: AMC 232-CID ENGINE

Engine / Vehicle Parameter	Model Year and Certification Standard																			
	1976 49 States					1976 California		1975 49 States				1975 California			1974 49 States				1970	1969	1968	1967
Vehicle Model	P[a]	P[a]	P[a]	G[b]	H[c]	P[a]	H[c]	G[b]	H[c]	P[a]	M[d]	H[c]	G[b]	H[e]	G[b]	H[f]	H[e]	U[g]	H[e]	R[h]	-	Re[i]
Transmission Type	A3	A3	A3	M3-OD	M3-OD	A3	M3	A3	M3	M3	M3	M3	A3	A3	A3	A3	A3	M3	M3	A	A	-
Vehicle Inertia Weight, lb	3000	3500	3500	3000	3500	3500	3500	3000	3500	3500	4000	3500	3000	3500	3000	3500	3500	3000	-	-	-	-
Rear Axle Ratio	2.53	2.73	3.08	3.08	3.08	3.08	3.08	2.73	3.08	3.08	3.54	3.08	3.08	3.08	2.73	3.31	2.73	4.27	-	-	-	-
Catalyst	No	No	No	No	No	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No
No. of Carburetor Venturi's	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	-	1	-
Carburetor Calibration, A / F																						
Idle: 0.7-lb / min air flow	13.1	13.1	13.1	12.5	12.0	13.3[j]	12.5	11.7	12.5	12.5	9.8[k]	11.5[k]	12.2[j]	12.2[j]	12.4	12.4	12.4	-	-	-	12.5	-
Off Idle: 1.5-lb / min air flow	14.2	14.2	14.2	15.8	15.6	12.9	15.8	14.4	14.4	14.4	14.4	13.2	13.0	13.0	14.7	13.6	14.7	-	-	-	14.5	-
Part Throttle: 4.0 lb / min air flow	15.8	15.8	15.8	16.8	16.0	15.8	16.8	15.8	16.0	16.0	16.0	15.6	15.6	15.6	17.4	15.5	17.4	-	-	-	15.5	-
WOT at Max.: 15 lb / min air flow	12.3	12.3	12.3	12.8	12.5	12.2	12.8	12.4	12.5	12.5	12.5	12.3	12.3	12.3	-	12.0	-	-	--	-	12.5	-
Basic Timing, crankshaft deg BTC	8	8	8	8	8	8	8	5	5	5	5	5	5	5	5	5	5	-	3	5	-	5
Centrifugal Advance, crankshaft deg																						
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.5	1.5	0.0	2.0	0.0	-	7.0	7.0	-	3.0
1500 rpm	6.0	6.0	6.0	6.0	6.0	6.0	6.0	7.0	7.0	7.0	6.0	9.5	9.5	9.5	7.0	10.0	7.0	-	12.5	12.5	-	10.0
2000 rpm	10.0	10.0	10.0	10.0	10.0	10.0	10.0	14.5	14.5	14.5	10.0	16.0	16.0	16.0	15.0	16.0	15.0	-	18.0	18.0	-	16.5
3000 rpm	11.5	11.5	11.5	11.5	11.5	11.5	11.5	15.0	15.0	15.0	11.5	16.0	16.0	16.0	15.0	16.0	15.0	-	22.0	22.0	-	20.0
4000 rpm	12.5	12.5	12.5	12.5	12.5	12.5	12.5	24.0	24.0	24.0	12.5	23.5	23.5	23.5	24.0	23.0	24.0	-	26.0	26.0	-	24.0
5000 rpm	12.5	12.5	12.5	12.5	12.5	12.5	12.5	28.0	28.0	28.0	12.5	26.0	26.0	26.0	28.0	26.0	28.0	-	26.0	26.0		26.0
Vacuum Advance, crankshaft deg																						
5 in. Hg	0.0	0.0	0.0	0.0	0.0	00.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0	-	0.0
6 in. Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0	-	0.0
8 in. Hg	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	5.0	5.0	5.0	-	6.5	6.5	-	6.5
10 in. Hg	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	10.0	10.0	10.0	-	11.5	11.5	-	11.5
12 in. Hg	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	-	15.0	15.0	-	15.0
15 in. Hg	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	15.5	15.5	15.5	-	20.0	20.0	-	20.0
20 in. Hg	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	15.5	15.5	15.5	-	22.0	22.0	-	22.0
EGR Valve Calibration[l]																						
Signal Vacuum To Open, in. Hg	2.0	2.0	2.0	2.0	2.0	2.0[m]	2.0[m]	3.0	3.0	3.0	-	2.0[m]	2.0[m]	2.0[m]	-	2.0[m]	2.0	-	-	-	-	-
Flow at 12-in. Hg, lb / min	2.1	2.1	2.1	2.1	2.1	2.1	2.1	0.75	0.75	0.75	-	2.9	1.9	1.9	-	2.2	2.2	-	-	-	-	-
Fuel Economy, mpg																						
City	19	17	18	17	17	15	16	19	18	18	14	14	17	16	15.9[n]	15.5[n]	14.7[n]	11.1[n]	-	-	-	-
Highway	25	23	22	30	25	19	20	24	26	21	19	22	23	19	-	-	-	-	-	-	-	-
Exhaust Emissions, g / m																						
HC	1.2	1.2	1.0	1.4	1.2	0.30	0.40	0.9	1.3	1.4	1.3	0.5	0.2	0.3	1.3[n]	2.4[n]	2.1[n]	1.7[n]	-	-	-	-
CO	8	15	10	14	11	7	6	8	12	15	6	7	6	7	15[n]	35[n]	25[n]	13[n]	-	-	-	-
NO_x	3.0	2.7	2.4	3.0	2.5	1.40	1.70	2.8	2.2	2.6	2.7	1.9	1.5	1.5	2.8[n]	1.5[n]	2.1[n]	1.9[n]	-	-	-	-

[a] Pacer

[b] Gremlin

[c] Hornet wagon

[d] Matador

[e] Hornet

[f] Hornet Sportabout

[g] Universal; calibrated to meet California emission standards

[h] Rogue

[i] Rebel

[j] At 4.0-lb/min flow rate

[k] At 0.5-lb/min flow rate

[l] AMC uses restrictor plates with some EGR systems.

[m] Signal Source differs from 49-states version.

[n] 1972 FTP.

TABLE 4-5. CERTIFICATION CALIBRATION DATA: AMC 258-CID ENGINE

Engine/Vehicle Parameter	Model Year and Certification Standard																						
	1976 49 States							1976 California		1975 49 States					1975 California		1974 49 States						1972
Vehicle Model	P^{a}	M^{b}	G^{c}	M^{b}	M^{b}	P^{a}	P^{a}	P^{a}	G^{c}	H^{d}	G^{c}	M^{e}	A^{f}	M^{b}	P^{a}	H^{g}	H^{g}	$H^{g,h}$	$H^{g,i}$	$H^{g,h}$	$G^{i,h}$	G^{i}	-
Transmission Type	A	A	M30D	M3	M3	A3	A3	A3	M30D	A3	M3	A3	M3	M3	M3	A3	A3	A3	A3	M3	M3	M3	-
Vehicle Inertia Weight, lb	3500	4000	3000	4000	4000	3500	3500	3500	3500	3500	3000	4000	4000	4000	3500	3500	3500	3500	3500	3500	3000	3000	-
Rear Axle Ratio	3.08	3.54	2.73	3.15	3.54	2.53	3.08	3.08	3.08	2.73	2.73	3.54	3.54	3.54	3.08	3.08	3.08	3.31	2.73	3.31	3.08	2.73	-
Catalyst	No	No	No	Yes	Yes	No	No	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
No. of Carburetor Venturi's	1	1	1	1	1	2	2	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-
Carburetor Calibration, A/F																							
Idle: 0.7-lb/min air flow	13.1	13.1	12.5	11.8	11.8	13.7^{i}	13.7^{i}	13.3^{i}	12.5	11.7	12.5	11.7	9.8^{j}	9.8^{j}	11.5^{j}	12.2^{i}	12.4	12.4	12.4	12.4	12.4	12.4	-
Off-Idle: 1.5-lb/min air flow	14.2	14.2	15.8	12.3	12.3	14.4	14.4	12.9	15.8	14.4	14.4	14.4	14.4	14.4	13.2	13.0	14.7	13.6	14.7	13.1	13.1	14.3	-
Part Throttle: 4.0-lb/min air flow	15.8	15.8	16.8	15.8	15.8	16.2	16.2	15.8	16.8	15.8	16.0	15.8	16.0	16.0	15.6	15.6	17.4	15.5	17.4	15.4	15.4	16.7	-
WOT at Max.: 15.0-lb/min air flow	12.3	12.3	12.8	12.1	12.1	12.4^{k}	12.4^{k}	12.2	12.8	12.4	12.4	12.4	12.4	12.4	12.3	12.3	-	12.0	-	12.2	12.2	-	-
Basic Timing, crankshaft deg BTC	8	8	6	6	6	8	8	8	6	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Centrifugal Advance, crankshaft deg																							
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.5	0.0	2.0	0.0	2.0	2.0	0.0	1.0
1500 rpm	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	7.0	7.0	6.0	6.0	6.0	9.5	9.5	7.0	10.0	7.0	10.0	10.0	7.0	7.0
2000 rpm	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	14.5	14.5	10.0	10.0	10.0	16.0	16.0	15.0	16.0	15.0	16.0	16.0	15.0	14.0
3000 rpm	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	15.0	15.0	11.5	11.5	11.5	16.0	16.0	15.0	16.0	15.0	16.0	16.0	15.0	20.0
4000 rpm	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	24.0	24.0	12.5	12.5	12.5	23.5	23.5	24.0	23.0	24.0	23.0	23.0	24.0	-
5000 rpm	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	28.0	28.0	12.5	12.5	12.5	26.0	26.0	28.0	26.0	28.0	26.0	26.0	28.0	-
Vacuum Advance, crankshaft deg																							
5 in. Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
6 in. Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
8 in. Hg	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	-
10 in. Hg	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	-
12 in. Hg	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	-
15 in. Hg	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	-
20 in. Hg	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	-
EGR Valve Calibration[l]																							
Signal Vacuum To Open, in. Hg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0^{m}	2.0^{m}	3.0	3.0	3.0	3.0	3.0	2.0^{m}	2.0^{m}	-	2.0^{m}	-	2.8^{m}	2.0^{m}	-	-
Flow at 12-in. Hg, cfm	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	0.75	0.53	0.85	0.85	0.85	2.9	1.9	-	2.2	-	2.2	2.2	-	-
Fuel Economy, mpg																							
City	17	16	20	17	14	17	16	15	16	17	21	16	15	15	15	14	14.3^{n}	12.5^{n}	13.8^{n}	11.7^{n}	13.2^{n}	15.6^{n}	-
Highway	22	19	31	20	18	23	20	19	26	25	30	19	21	21	23	22	-	-	-	-	-	-	-
Exhaust Emissions, g/m																							
HC	1.1	1.1	0.8	0.6	0.5	1.1	1.1	0.3	0.3	0.9	1.3	1.1	1.3	0.7	0.3	0.2	2.3^{n}	2.3^{n}	1.7^{n}	2.6^{n}	2.1^{n}	1.6^{n}	
CO	12	12	6	12	6	14	13	5.4	6.4	6	14	7	6	4	6.3	5.9	35^{n}	31^{n}	22^{n}	22^{n}	25^{n}	14^{n}	-
NO_x	3.1	2.9	2.1	1.9	2.3	2.2	2.2	1.6	1.6	2.6	2.3	1.9	2.7	2.4	1.9	1.5	2.6^{n}	2.0^{n}	2.3^{n}	1.8^{n}	1.2^{n}	2.1^{n}	

[a] Pacer
[b] Matador
[c] Gremlin
[d] Hornet hatchback
[e] Matador wagon
[f] Ambassador
[g] Hornet
[h] Calibrated to meet California emission standards
[i] At 1.0-lb/min flow rate.
[j] At 0.5-lb/min flow rate.
[k] At 23-lb/min flow rate.
[l] AMC uses restrictor plates
[m] Signal source differs from 49-states version.
[n] 1972 FTP

The control unit is completely solid state and permanently sealed in a potting material to resist vibration and moisture. It has built in current regulation and reverse polarity as well as transient over-voltage protection. The ignition coil is an oil filled, hermetically sealed unit of standard construction. The distributor is also of conventional construction, except that an electromagnetic sensor and trigger wheel replace the usual contact points, capacitor, and distributor cam.

Two spark advance systems, centrifugal and vacuum, are used to establish the optimum spark timing required for various engine speed and load conditions. Both systems are conventional; however, the centrifugal advance system rotates the trigger wheel with respect to the distributor shaft rather than the cam as in breaker point ignition systems. The vacuum advance system moves the electromagnetic sensor to effect its timing changes.

4.1.3.4.2 Spark Timing Control Devices

As indicated in Tables 4-1 and 4-2, TCS advance is used on all 1974 AMC 6-cylinder engines. For 1975 and 1976, only California vehicles incorporate the system, and of the earlier model years only selected engines use the system, as shown in the tables. The objective of TCS is to reduce NO_x by lowering the peak combustion temperature during the piston power stroke. The system accomplishes this function by disabling vacuum spark advance below 35 mph for automatic transmission vehicles and in all gears except the final drive gear for manual transmission vehicles. The TCS system is implemented by a solenoid-controlled valve which blocks the distributor vacuum source and vents the distributor side of the vacuum line to atmosphere when the solenoid is energized. Solenoid actuation is controlled by a pressure switch which senses governor oil pressure on automatic transmissions and by shift linkage position on manual transmissions.

For better vehicle driveability during engine warmup, the TCS system is provided with a coolant temperature override (CTO) switch, which senses coolant temperature and provides full intake manifold vacuum advance to the distributor until the coolant temperature reaches a preset level. For 1974 California 6-cylinder manual transmission vehicles, the actuation temperature is $115^{\circ}F$, while for other AMC vehicle/engine/year combinations the temperature is $160^{\circ}F$.

The 1970 model year 232-CID 6-cylinder engine incorporates a distributor deceleration valve to aid in the control of HC in vehicles equipped with manual transmissions. The valve is actuated by manifold vacuum and provides full intake manifold vacuum advance to the distributor in place of carburetor ported vacuum during deceleration.

4.1.3.4.3 Spark Advance Schedules

The spark advance schedules of the 232- and 258-CID engines with automatic and manual transmission are presented in Tables 4-4 and 4-5, which show the centrifugal and vacuum advance as a function of engine rpm and distributor vacuum. For examination of the trends, the centrifugal and vacuum advance settings of the 232-CID engine are shown in Figure 4-1 and 4-2 as a function of model year. The 258-CID engine exhibits the same curve structure; however, basic ignition timing, which is included in the centrifugal schedule, is generally slightly less for the 258-CID unit, as may be seen by comparing Tables 4-4 and 4-5.

Examination of Figures 4-1 and 4-2 indicates the relative retardation of ignition timing that has taken place over the years in order to control exhaust emissions. Depending on engine speed, a relative centrifugal retardation of up to 7 deg. has been used for some model years since 1969, while vacuum advance shows roughly equal decreases.

The impact on ignition timing because of the introduction of EGR systems used as an aid in meeting Federal NO_x standards instituted in 1973 is clearly seen in Figure 4-1. As shown in the figure, a difference of as much as 4 deg of ignition advance is attributable to the use of EGR in the 1973 vehicles. While this difference can be attributed entirely to the use of EGR, the change in the absolute level of centrifugal advance is dependent on another factor. The use of TCS on the 232-CID and 258-CID engines, as indicated in Tables 4-1 and 4-2, has the effect of modifying the seeming increases in ignition advance exhibited in Figure 4-1. This occurs because TCS modulates the vacuum advance schedule in the on/off manner explained previously and effectively reduces total ignition advance over a portion of the vehicle operating envelope.

Relative ignition retardation for model years earlier than 1973 (1971 in California) is a result of efforts to control HC and CO emissions. The rationale is based on producing higher exhaust temperatures

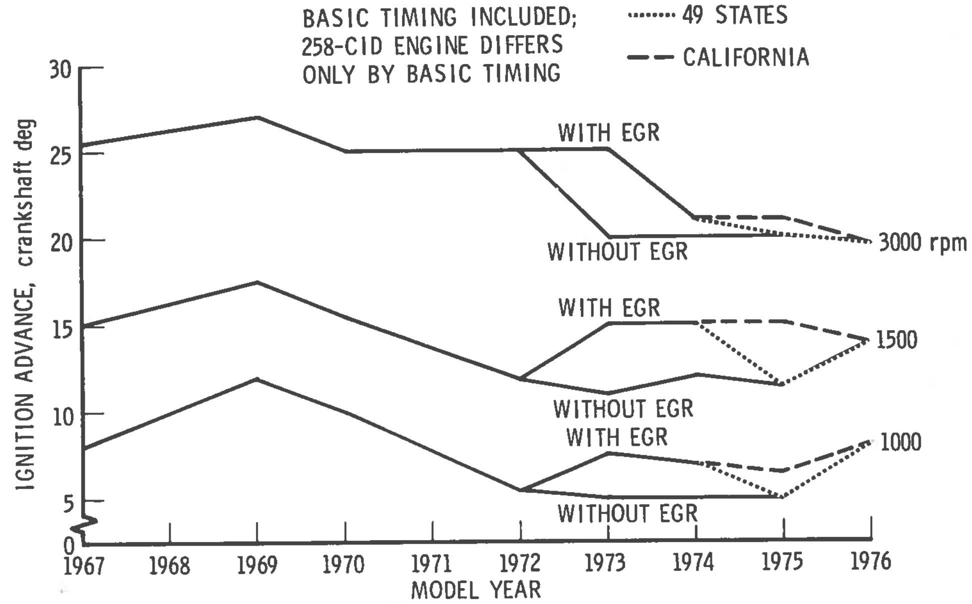


FIGURE 4-1. CENTRIGUGAL SPARK ADVANCE SCHEDULE: AMC 232-CID ENGINE

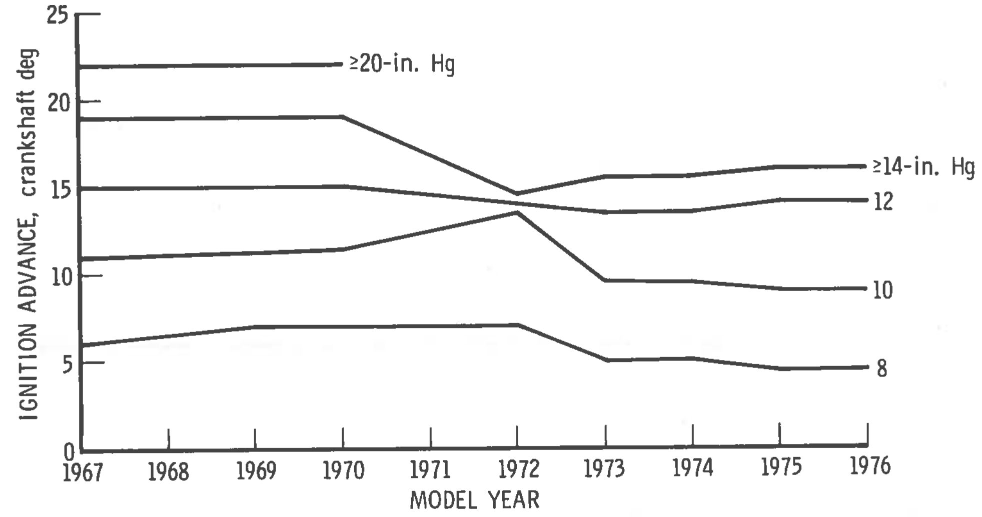


FIGURE 4-2. VACUUM SPARK ADVANCE SCHEDULE: AMC 232- AND 258-CID ENGINE

and continuing combustion in the exhaust system because of late ignition of the charge.

4.1.3.5 Exhaust Gas Recirculation

4.1.3.5.1 Design Features

As indicated in engine specification tables, recent AMC vehicles are equipped with an EGR system to control NO_x formed by high-peak combustion temperatures. The EGR system performs its function by diluting the engines' air/fuel intake charge with a metered amount of exhaust gas. Since the exhaust gas is inert in the sense that it cannot burn and because it is considerably cooler than combusting gases, the peak temperature of the combustion process is lowered, and formation of NO_x is inhibited.

In vehicles equipped to meet Federal emission standards, the EGR system consists of a vacuum-controlled diaphragm-actuated flow control valve, a coolant temperature override switch, and connecting hoses. The valve is mounted on the side of the intake manifold on the 232- and 258-CID engines, and a passage in the intake manifold directs exhaust gas from below the heat riser area to the EGR valve. When the valve is in the open position, exhaust gas passes through the valve and through additional intake manifold passages to a position below the carburetor, where the exhaust gas is mixed with the incoming air/fuel charge.

EGR valve position is controlled by vacuum obtained from a special fitting on the carburetor which provides "ported" (above the throttle plate) vacuum. With the throttle closed, ported vacuum is zero, and no EGR takes place. As the throttle is opened, the throttle plate crosses the carburetor vacuum port, and carburetor vacuum is provided to the EGR valve. The vacuum signal then overcomes the EGR diaphragm spring tension, which pulls the EGR valve pintle from its seated position and allows exhaust gas to mix with the fuel/air intake charge.

The EGR CTO switch is connected in series between the carburetor ported vacuum fitting and the EGR valve. It is located at the left front side of the cylinder block on all AMC 6-cylinder engines and provides an on-off switching of vacuum to the EGR valve based on sensed coolant temperature. For 1975 and 1976, coolant temperatures below 160°F on most lighter weight AMC 49-states vehicles, and 115°F on heavier cars and all California vehicles, causes vacuum to the EGR valve to be blocked. This switching action precludes the use of EGR during the early warmup periods when vehicle driveability is most adversely affected by EGR and when it is least needed because of lower engine operating temperatures.

The major difference between the California and 49-states EGR systems is an exhaust backpressure sensor and control valve which is added to the California vehicles. The exhaust backpressure sensor consists of a tube which projects into an engine exhaust passage. The tube is connected to and modulates the position of a control valve which is placed in series with the vacuum line between the EGR CTO switch and the EGR valve. The backpressure sensor and control valve has the effect of making EGR flow proportional to exhaust backpressure, which is, in turn, approximately proportional to engine load, combustion temperature, and the rate of formation of NO_x.

4.1.3.5.2 EGR Valve Calibration

Ideally, the EGR flow rate should be tailored to individual engine/vehicle combinations and characterized as a percentage of total exhaust flow for various engine load conditions. However, because of their multi-parameter dependence, such curves are generally not available, and EGR valve flow curves are usually given simply in terms of valve air flow at a constant vacuum as a function of applied signal vacuum. In addition, true EGR flow rates are obscured because restrictor plates are used with some vehicles to limit maximum EGR flow. Therefore, these data are useful for relative comparisons of flow rates only if the overall EGR systems are the same. This should be kept in mind when referring to the data presented in Tables 4-4 and 4-5, which give the valve flow rates and signal vacuum required to initiate EGR. Integrated average EGR flow rates over the Federal driving cycle are presented in the discussion of fuel economy and emission effects (Section 4.1.3.9).

4.1.3.6 Secondary Air Injection

Secondary air injection is used on some of the 232- and 258-CID engines as indicated in Tables 4-1 and 4-2. The system is comprised of a belt driven air pump, a manifold vacuum-controlled diverter or by-pass valve, an air distribution manifold, air injection tubes, and connecting hoses.

Air is discharged at a rate of 19 cu in. per engine revolution from the air pump to the diverter valve, where it is either directed to the air distribution manifold or dumped to atmosphere, depending on the engine operating conditions. System air pressure is regulated at approximately 5 psi by a relief valve incorporated in the diverter. Check valves prevent reverse flow of exhaust gases, which could damage the pump.

Under normal operation, the diverter valve is in the closed position, and air is routed to the injection tubes where it is discharged into each exhaust port area. As the air mixes with hot unburned gases, further burning of the combustion mixture takes place, thereby effecting a reduction of unburned HC and CO emissions in the exhaust stream. Conversely, under conditions of rapid throttle closure, extremely rich mixtures of hot exhaust gases can accumulate in the exhaust ports, and secondary air injection under these conditions will cause backfire. To preclude this occurence, the diverter valve is opened by the high manifold vacuum associated with throttle closure, and the air pump output is momentarily discharged to the atmosphere.

Secondary air injection has been used on many of the AMC engines shown in the engine summary tables. However, on vehicles using so called "Engine Mod" control systems, secondary air injection is not used, and carburetors are set to an air/fuel ratio slightly leaner than vehicles using secondary air.

4.1.3.7 Catalytic Converter

Oxidizing catalytic converters, first introduced in the 1975 model year, are used on all 1975 and 1976 AMC cars built for sale in California and on some 49-states automobiles as indicated in Table 4-1 and 4-2. The catalyst material is an alloy of platinum and palladium deposited on beads of alumina. The beads are contained in a canister which is mounted under the floor of the vehicle. The beads can be replaced; however, there is no scheduled maintenance since the catalyst is designed to last the life of the car. No over-temperature or other warning devices are used by AMC for the catalyst system.

4.1.3.8 Crankcase and Evaporative Emission Control

The PCV system has been in use since prior to 1968 and performs the function of preventing combustion blowby gases from entering the atmosphere.

Evaporative emission control is used on all 1970 and later model California vehicles and in the 1971 and subsequent model year 49-states vehicles. The design features and operating characteristics of these systems are described in Section 3.

4.1.3.9 Fuel Economy and Emissions

The manner in which engine control practices have affected city fuel economy over past years is presented in Tables 4-4 and 4-5 and in Figures 4-3 through 4-6 (Refs 4-15 through 4-21). Each figure represents data associated with a specific engine and transmission combination and gives fuel economy as a function of model year. In order to place year-to-year fuel economy data on an equivalent basis and thereby aid the identification of engine control induced economy trends, a normalization procedure has been applied to obtain the data exhibited in the figures. Specifically, the fuel economy data given in the tables have been normalized to a standard vehicle inertia weight and axle ratio as indicated by notes on each figure. As described in Section 3, the normalization method is based on fuel economy-to-inertia weight and fuel economy-to-axle ratio sensitivity coefficients derived from recently published data. In addition, the fuel economy of the 1973 and 1974 model years was increased by 5 percent to account for the differences in the 1972 versus 1975 FTP.

As the 232- and 258-CID engines have in recent years shared common distributor, carburetor, and EGR systems and calibrations, they exhibit very similar fuel economy trends. Typically, each of the four 49-states fuel economy histories show rather large drops in fuel economy from 1973 to 1974 followed by a recovery in 1975 and generally small decreases in 1976. The one exception is shown in Figure 4-3, which presents data for the 258-CID engine with automatic transmission. In this figure, an inconsequentially small 1975 to 1976 gain in fuel economy, rather

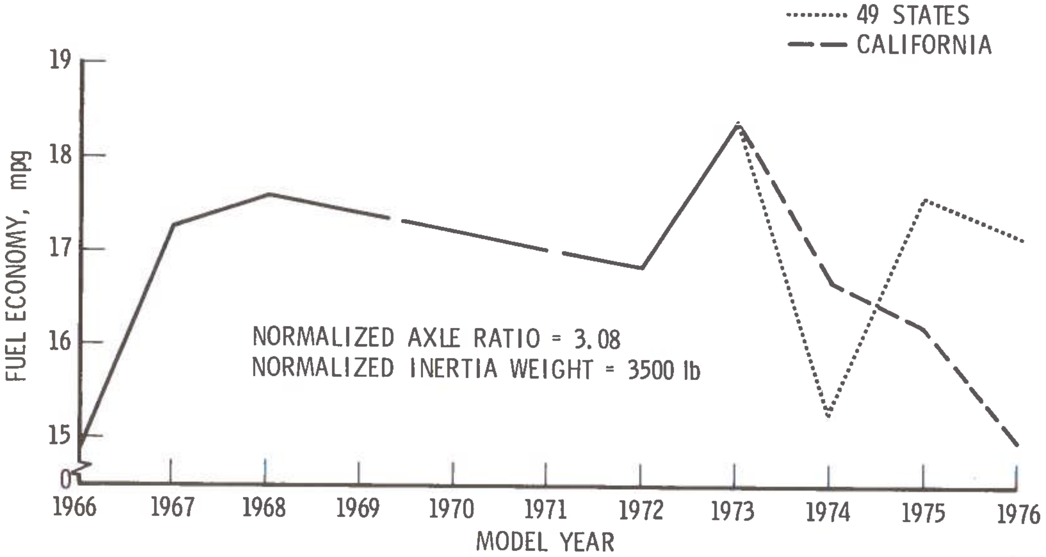


FIGURE 4-3. NORMALIZED AVERAGE CITY FUEL ECONOMY: AMC 232-CID ENGINE WITH AUTOMATIC TRANSMISSION

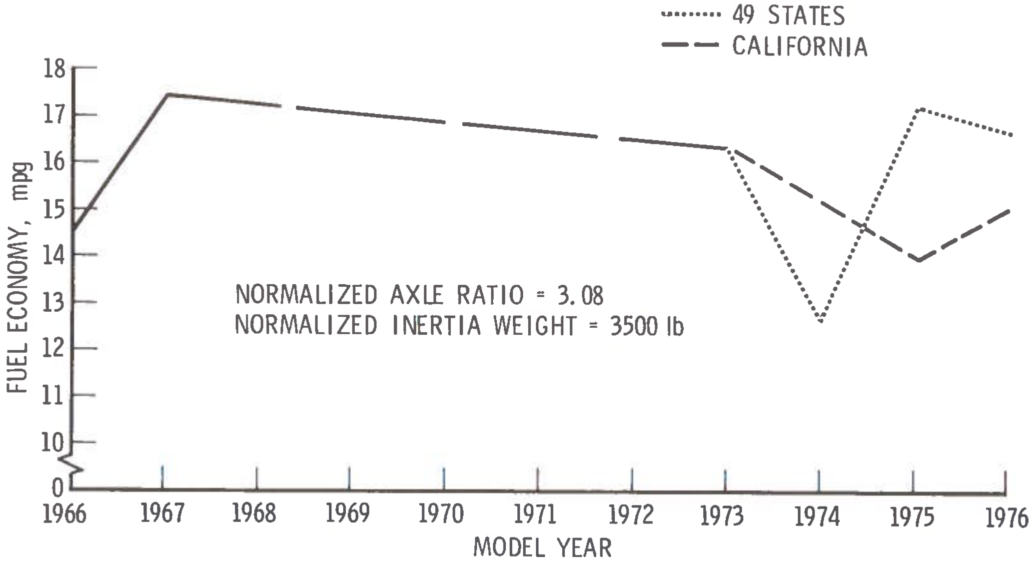


FIGURE 4-4. NORMALIZED AVERAGE CITY FUEL ECONOMY: AMC 232-CID ENGINE WITH MANUAL TRANSMISSION

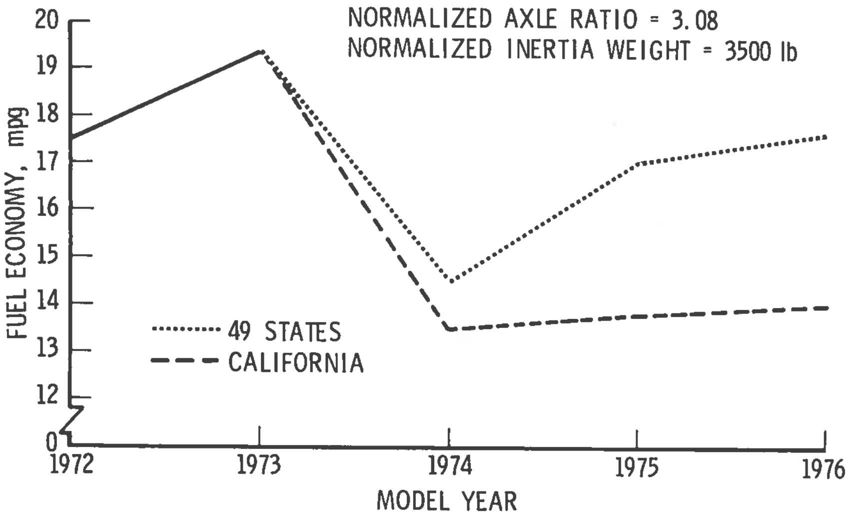


FIGURE 4-5. NORMALIZED AVERAGE CITY FUEL ECONOMY: AMC 258-CID ENGINE WITH AUTOMATIC TRANSMISSION

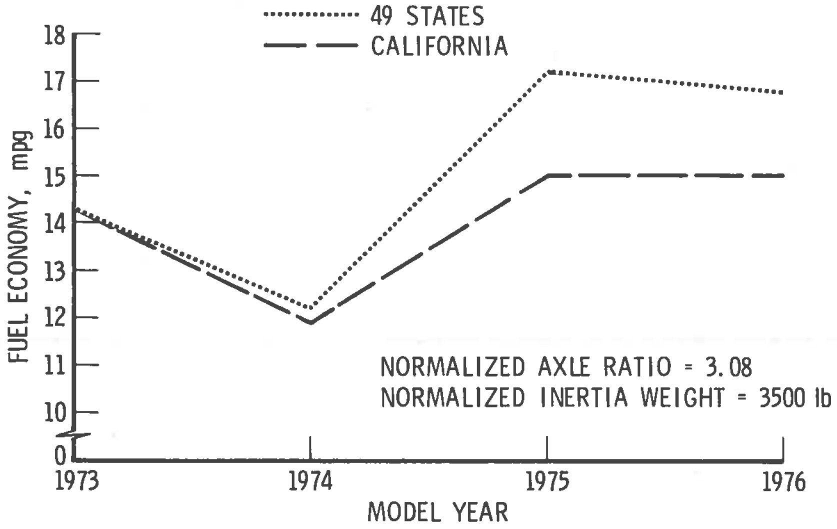


FIGURE 4-6. NORMALIZED AVERAGE CITY FUEL ECONOMY: AMC 258-CID ENGINE WITH MANUAL TRANSMISSION

than a small loss, is shown.

Examination of year-to-year engine control system applications and calibrations provides a rationale for the subject economy trends. Starting with the imposition of Federal NO_x standards in 1973, AMC introduced EGR on the 6-cylinder engines but limited its use to the relatively heavy Matador series vehicle. As indicated in Tables 4-1 and 4-2, the use of EGR was expanded in 1974, and in 1975 all 232- and 258-CID engines were equipped with EGR systems which they retain in 1976. As indicated in the tables, all California vehicles are equipped with EGR for the 1974 through 1976 model years.

Correlated with the wider use of EGR and attendant changes of volumetric efficiency are the aforementioned variations in fuel economy. For Federal vehicles, the year in which the highest EGR flow rates were used is 1974, and this is the worst year from a fuel economy viewpoint. In the 1974 model 49-states vehicles, the integrated and averaged EGR flow accounts for roughly 15 percent of the total engine flow during the Federal Driving Cycle. The amount decreases to approximately 12 percent in 1975 and increases to roughly 13.5 percent in the 1976 model year 49-states vehicles. Comparable integrated average EGR levels for vehicles certified for sale in California are 20, 16, and 16 percent for respective 1974, 1975, and 1976 model years (Ref. 4-22). The higher 1974 EGR levels are required because of EGR valve deterioration associated with the extensive use of leaded gasoline in 1974.

Tables 4-4 and 4-5 as well as Figures 4-1 and 4-2 which show the ignition timing used with the subject engines, further completes the fuel economy/engine control system correlation picture. As shown in Figure 4-1, the centrifugal ignition advance remains relatively constant between 1973 and 1974 for both EGR and non-EGR equipped vehicles. For 1975, the curve shows a marked decrease in advance for the 49-states vehicles, while the California vehicles show a relatively higher advance in the important mid-speed range of the driving cycle. This at first may be misleading as overall 49-states ignition advance seems to decrease during years of improving 49-states fuel economy. Also, the California vehicles which are subject to more stringent emission standards than their 49-states counterparts seem to show more ignition advance. However, examination of Tables 4-1 and 4-2 reveals that the 1975 and 1976 49-states vehicles dispense with TCS which is used on all AMC 6-cylinder engines certified to 1974 Federal standards and on all 1975 and 1976 California vehicles. The net result is that while the ignition advance levels of the 49-states calibrations may seem high during 1974, they are actually greatly depressed compared with 1975 and 1976 levels. This results because a significant amount of vacuum advance defeat is imposed by TCS over much of the vehicle operating envelope. California vehicle economy trends do not show the sharp 1975 fuel economy rebound from 1974 lows as exhibited by 49-states counterparts. In this case, the continued use of TCS on California vehicles again provides the explanation. Thus, recent overall changes in ignition advance and EGR flow rates correlate quite well on a year-to-year basis with fuel economy improvements.

In general, recent 232- and 258-CID part throttle carburetor calibrations do not vary widely from settings used in non-emission control years. In the 1974 model year, wider departures were used as shown in Tables 4-4 and 4-5. However, these variations were more likely important to emission control than fuel economy. Ignition timing changes along with intake charge dilution remain as primary fuel economy determinants.

The fuel economy data shown in Figures 4-3 through 4-6 for model years prior to 1973 were obtained from tests of used vehicles as explained in Section 3. These data are included to provide a rough perspective for more recent data. As indicated 1975 and 1976, fuel economy figures compare favorably to available pre-emission control figures for the subject AMC engines.

4.1.4 AMC 304-CID Engine

4.1.4.1 Engine Modifications

As on the 6-cylinder engines discussed in Section 4.1.3.1, AMC employs a low-quench, wedge combustion chamber configuration to minimize the formation of HC and CO emissions. For the model years shown in Table 4-3, there have been no changes in the design of the combustion chamber of the 304-CID engine used in 49-states vehicles. However, California cars use a considerable amount of intake-exhaust valve overlap (71.5 deg) in 1972 for NO_x control purposes. As seen in Table 4-3, the use of an EGR system to control NO_x in 1974, 1975, and 1976 allowed restoration of valve timing on California vehicles to values previously used only on 49-states cars.

4.1.4.2 Intake System

The AMC 304-CID V-8 employs a thermostatically controlled air cleaner much like the one used on the AMC 6-cylinder engines described in Section 4.1.3.2. The major difference in the two systems is the manner in which motive force is applied to the air control valve.

On the V-8 engine, air valve movement is accomplished using a vacuum motor rather than a spring actuator. To effect control over the vacuum motor, the thermal sensor incorporates an air bleed valve which regulates the amount of vacuum supplied to the motor. Temperature operating points are the same as described for the AMC 6-cylinder engines.

The V-8 engine also uses a heat riser system similar in function to the 6-cylinder system; however, the V-8 unit does not incorporate a stainless steel "hot spot", as the 6-cylinder engine does.

4.1.4.3 Carburetor

4.1.4.3.1 Design Features

The AMC 304-CID V-8 engine is fitted with a two-venturi down-draft carburetor as shown in Table 4-5. In addition to the float and choke circuits, four metering circuits are used. The idle circuit provides an air/fuel mixture for idle and low speed performance; the main metering circuit provides economical mixtures for cruising speeds; the pump circuit injects additional fuel during low speed acceleration; and the power enrichment circuits provides a fuel-rich mixture when high engine power output is required.

The float circuit consists of a conventional float and lever assembly controlling a fuel inlet needle to maintain a specific fuel level in the fuel bowl. The correct fuel level, in turn, enables the basic fuel metering circuits to deliver the proper mixture to the engine.

Fuel for idle operation is metered by a series of calibrated restrictions and is mixed with air entering idle passages through air bleeds located in the main carburetor body. The air/fuel mixture then moves through idle passages past a set of idle transfer slots and past the idle mixture adjusting screw, which controls the amount of mixture discharged below the throttle plate. During part-throttle, low-speed operation, the throttle plate uncovers the idle transfer slots, subjecting them to intake manifold vacuum which increases the amount of air/fuel mixture supplied to the engine. Idle mixture limiter caps are provided on all model year engines listed in Table 4-3, and throttle stop solenoids are used on 1974 and later model year vehicles with automatic transmissions. Dashpots are used with manual transmission models.

As engine speed increases, air passing through a booster venturi causes a partial vacuum which induces fuel flow in the main metering system. Fuel is then metered by the main jets and mixed with air provided via main air bleeds. These bleeds meter an increasing amount of air with increasing venturi vacuum and maintain the economical cruise mixture mentioned previously.

When the throttle valves are opened rapidly, airflow through the carburetor responds very quickly. However, since the fuel has a much higher mass than air, there is a brief time lag before fuel can be accelerated to sufficient velocity to maintain the proper air/fuel ratio. During this time lag a pump circuit supplies the required fuel until the proper air/fuel ratio can be maintained by the other metering circuits. The pump circuit is implemented by a diaphragm using a spring-driven intake stroke, with the output or discharge stroke actuated mechanically by connection to the throttle linkage.

A power enrichment circuit supplies extra fuel during prolonged heavy load or high-speed engine operation. The increased fuel required for enriched mixtures is provided by a two-stage manifold vacuum-actuated power valve. As lower values of manifold vacuum associated with increasing engine loads occur, an imbalance of spring versus vacuum-derived forces results. This causes the power valve to open to its first stage and allows an increased rate of fuel flow in the main metering circuit. Still lower values of manifold vacuum allow the power valve to open further to a second stage and deliver additional fuel to the main metering circuit. As loads decrease, increased intake manifold vacuum overcomes spring forces, and the power valve closes.

The choke circuit is conventional and is implemented by a two-stage vacuum modulator and a bimetallic spring. Premature choke opening is precluded by a thermostatic bypass valve which allows unheated air to enter the choke housing until heated air reaches 75°F. Electric assist is not used.

4.1.4.3.2 Carburetor Calibration

Carburetor calibration data for the 304-CID engine are listed in Table 4-6, which shows the mean air/fuel ratio at idle, off-idle, part-throttle, and WOT. While the tolerance band of the air/fuel ratio curves has remained near ± 5 percent over the past several years, AMC has reduced the production tolerances of the air/fuel ratio excursions. In general, the air/fuel ratio in the off-idle and part-throttle operating regime increased moderately between 1974 and 1975, followed by a decline in 1976. Conversely, the idle air/fuel ratio was reduced in 1975 and again in 1976, as part of the AMC overall approach of emission control with catalyst systems.

4.1.4.4 Ignition System

4.1.4.4.1 Design Features

A functionally similar BID ignition system used on the AMC 6-cylinder engines and described in Section 4.1.3.4 is used in the 1975 and 1976 model year 304-CID engine. As with the 6-cylinder engines in model years prior to 1975, a conventional breaker-point ignition system is used.

TCS is employed on model years of interest as indicated in Table 4-5. Coolant temperature override is a part of the system and is also described in the section dealing with the 6-cylinder ignition systems.

4.1.4.4.2 Spark Advance Schedules

Figures 4-7 and 4-8 show typical centrifugal and vacuum advance schedules versus model year for the 304-CID engine. Introduction of EGR in 1973 is evidenced by increased centrifugal advance relative to 1972 levels. These changes reflect the shift to EGR control of NO_x in place of a retarded ignition control philosophy. However, as in the case

TABLE 4-6. CERTIFICATION CALIBRATION DATA: AMC 304-CID ENGINE

ENGINE / VEHICLE PARAMETER	Model Year and Certification Standard																									
	1976 49 States				1976 California				1975 49 States					1975 California				1974 49 States						1972	1970	1970
Vehicle Model	H[a]	H[b]	M[c]	G[d]	G[d]	H[b]	M[c]	H[e]	M[f]	A[g]	H[e]	A[h]	G[d]	A[g]	G[d]	H[a]	M[f]	M[f]	J[i]	M[c]	U[j]	M[f]	J[i, k]	-	HJ[l]	HJ[l]
Transmission Type	A3	A3	A3	M3	A3	A3	A3	M3	A3	A3	M3	A3	M3	A3	M3	M3	A3	A3	A3	A3	M3	A3	A3	A	A	M
Vehicle Inertia Weight, lb	3500	4000	4500	3500	3500	4000	4500	3500	4500	4500	3500	4500	3500	4500	3500	3500	4500	4000	3500	4500	3000	4000	3500	-	-	-
Rear Axle Ratio	3.15	2.87	3.54	2.87	2.87	3.15	3.54	3.54	3.15	3.54	3.54	3.54	3.15	3.54	3.15	3.54	3.15	3.15	3.15	3.54	3.73	3.15	2.87	-	-	-
Catalyst	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	-	-	-
No. of Carburetor Venturi's	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	-	-	-
Carburetor Calibration, A / F																										
Idle: 1.0 lb / min air flow	11.9	11.9	11.9	12.6	11.9	11.9	11.9	12.6	12.1	12.1	12.4	12.1	12.4	12.1	12.4	12.4	12.1	13.3	13.3	13.3	12.5	13.3	13.3	-	-	-
Off Idle: 3.0 lb / min air flow	14.3	14.3	14.3	14.7	14.3	14.3	14.3	14.7	15.0	15.0	15.5	15.0	15.5	15.0	15.5	15.5	15.0	14.9[m]	14.9[m]	14.9[m]	14.5[m]	14.9[m]	14.9[m]	-	-	-
Part Throttle: 10.0 lb / min air flow	15.5	15.5	15.5	16.2	15.5	15.5	15.5	16.2	15.9	15.9	16.1	15.9	16.1	15.9	16.1	16.1	15.9	15.6	15.6[m]	15.6[m]	15.6	15.6	15.6	-	-	-
WOT at Max.: 22.0 lb / min air flow	13.4	13.4	13.4	12.9	13.4	13.4	13.4	12.9	13.2	13.2	12.9	13.2	12.9	13.2	12.9	12.9	13.2	13.7	13.7	13.7	13.7	13.7	13.7	-	-	-
Basic Timing, crankshaft deg BTC	10	10	10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Centrifugal Advance, crankshaft deg																										
1000 rpm	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0	3.5	3.0	3.5	3.0	3.5	3.5	3.0	5.0	5.0	5.0	3.0	5.0	2.0	0.0	2.0	2.0
1500 rpm	7.5	7.5	7.5	10.0	10.0	10.0	10.0	10.0	16.0	16.0	11.5	16.0	11.5	16.0	11.5	11.5	16.0	16.0	16.0	16.0	11.0	16.0	9.5	7.0	10.0	10.0
2000 rpm	10.5	10.5	10.5	15.0	15.0	15.0	15.0	15.0	19.0	19.0	18.0	19.0	18.0	19.0	18.0	18.0	19.0	18.0	18.0	18.0	18.0	18.0	18.0	14.0	14.0	14.0
3000 rpm	16.0	16.0	16.0	21.0	21.0	21.0	21.0	21.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	22.0	23.0	20.0	20.0
4000 rpm	22.0	22.0	22.0	26.0	26.0	26.0	26.0	26.0	30.0	30.0	29.5	30.0	29.5	30.0	29.5	29.5	30.0	30.0	30.0	30.0	30.0	30.0	26.0	-	25.0	25.0
5000 rpm	-	-	-	-	-	-	-	-	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	26.0	-	26.0	26.0
Vacuum Advance, crankshaft deg																										
5 in. Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 in. Hg	2.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	0.5	2.0	0.5	2.0	0.5	0.5	2.0	2.0	2.0	2.0	0.0	2.0	0.0	0.0	0.0	0.0
8 in. Hg	6.0	6.0	6.0	5.0	5.0	5.0	5.0	5.0	6.0	6.0	5.0	6.0	5.0	6.0	5.0	5.0	6.0	6.0	6.0	6.0	0.5	6.0	5.0	5.0	0.0	6.5
10 in. Hg	10.5	10.5	10.5	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	0.0	11.0
12 in. Hg	14.5	14.5	14.5	15.0	15.0	15.0	15.0	15.0	14.5	14.5	15.0	14.5	15.0	14.5	15.0	15.0	14.5	14.0	14.0	14.0	15.0	14.0	15.0	15.0	0.0	14.5
15 in. Hg	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	16.0	15.0	16.0	16.0	0.0	18.0
20 in. Hg	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	16.0	15.0	16.0	16.0	0.0	18.0
EGR Value Calibration[n]																										
Signal Pressure To Open, in. Hg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0[o]	2.0[o]	2.0[o]	2.0[o]	-	-	-	-	-	2.0[o]	-	-	-
Flow at 12-in. Hg, cfm	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	-	-	-	-	-	1.8	-	-	-
Fuel Economy, mpg																										
City	13	13	13	16	12	12	11	13	13	13	14	13	14	12	13	13	13	12.4[p]	12.1[p]	12.3[p]	11.5[p]	11.6[p]	11.1[p]	-	-	-
Highway	19	18	16	22	20	17	15	16	19	16	19	17	20	17	21	20	18	-	-	-	-	-	-	-	-	-
Exhaust Emissions, g / m																										
HC	0.4	0.6	0.4	0.5	0.3	0.5	0.5	0.6	0.4	0.4	0.5	0.4	0.4	0.2	0.5	0.6	0.5	2.7[p]	3.3[p]	2.6[p]	3.0[p]	3.2[p]	2.9[p]	-	-	-
CO	3	10	9	8	3	3	7	5	4	6	5	5	4	3.6	6.3	7.4	3.7	22[p]	24[p]	21[p]	20[p]	26[p]	25[p]	-	-	-
NO_x	2.7	2.2	2.3	2.3	1.1	2.0	1.7	1.9	2.9	2.5	2.8	2.8	2.8	1.9	1.7	1.9	1.9	2.3[p]	2.4[p]	2.5[p]	2.3[p]	2.6[p]	1.2[p]	-	-	-

[a] Hornet

[b] Hornet wagon

[c] Matador wagon

[d] Gremlim

[e] Hornet hatchback

[f] Matador

[g] Ambassador sedan

[h] Ambassador wagon

[i] Javelin

[j] Universal

[l] Hornet; Javelin

[k] Calibrated to meet California emission standards

[m] At 2.2-lb / min flow rate

[n] AMC uses restrictor plates with some EGR systems.

[o] Signal source differs from 49-states version

[p] 1972 FTP

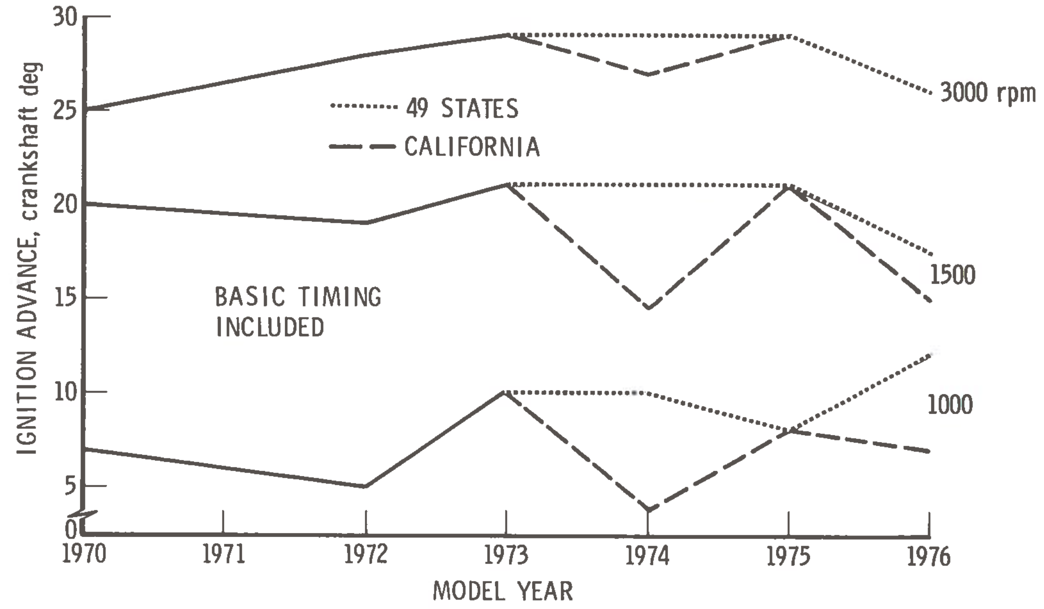


FIGURE 4-7. CENTRIGUGAL SPARK ADVANCE SCHEDULE: AMC 304-CID ENGINE WITH AUTOMATIC TRANSMISSION

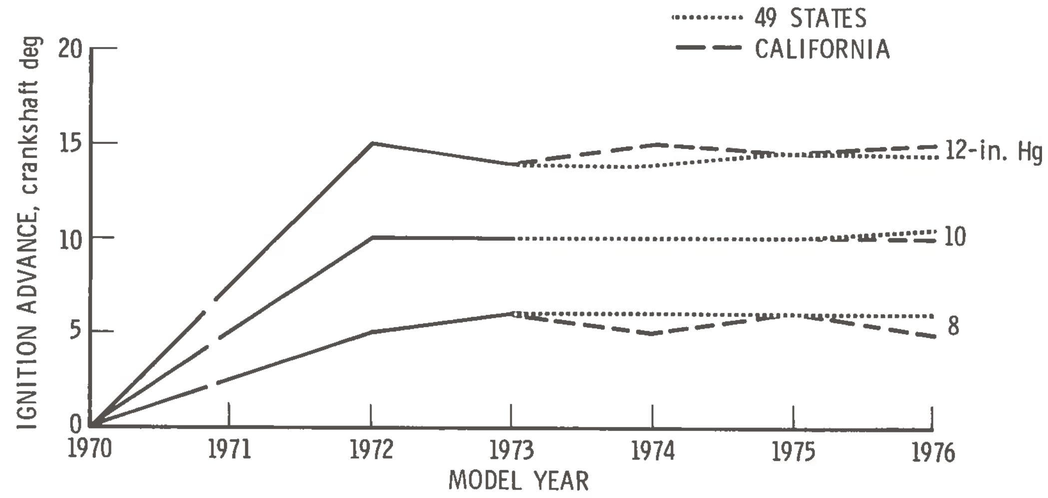


FIGURE 4-8. VACUUM SPARK ADVANCE SCHEDULE: AMC 304-CID ENGINE WITH AUTOMATIC TRANSMISSION

of the 6-cylinder ignition advance history, some model year advance levels are partially offset by use of TCS. Table 4-3 details the use of TCS in each model year.

Institution of the California 1974 2-g/m NO_x standard in terms of its effect on centrifugal ignition advance is clearly discernable in Figure 4-7. Restoration of centrifugal advance on the California vehicles in 1975 is indicative of overcontrolled 1974 NO_x emissions as explained in Section 4.1.4.9.

4.1.4.5 Exhaust Gas Recirculation

The functional and operating characteristics of the EGR system are the same as for the 6-cylinder engines described in Section 4.1.3.5. EGR CTO is set at 115° F for 1974 through 1976, and EGR is used on all 304-CID V-8 engines. California and 1976 49-states vehicles use the previously described exhaust backpressure sensor. While the EGR valve calibration data listed in Table 4-6 indicate no change in the valve flow rate between 1975 and 1976, the EGR rates vary from year to year because of the use of restrictor plates with different orifice sizes. This is further discussed in Section 4.1.4.9.

4.1.4.6 Secondary Air Injection

As indicated in Table 4-3, most 1974 through 1976 model 304-CID engines are equipped with secondary air injection. The system used on this engine is essentially the same as the 6-cylinder unit described in Section 4.1.3.6, except for detail differences and the amount of air delivered by the pump. On V-8 engines, air is delivered at 23.75 cu in./engine revolution rather than at the 19 cu in./revolution rate used with 6-cylinder models. The pumps are the same on the various engines, and delivery rate differences are a result of different sizes of pump drive pulleys.

4.1.4.7 Catalytic Converter

The same type of converter is used on the AMC 304-CID V-8 as described previously in Section 3.2.3.2.7. However, 49-states vehicles use a single converter, single muffler exhaust system while California cars employ two converters in series with a single muffler exhaust system.

4.1.4.8 Crankcase and Evaporative Emission Control

The PCV and evaporative emission control systems are functionally the same as previously described in Section 4.1.3.8.

4.1.4.9 Fuel Economy and Emissions

Figures 4-9 and 4-10 present normalized, average fuel economy histories of 304-CID automatic and manual transmission vehicles based on the data in Table 4-6 (Refs. 4-15 through 4-21). These curves show essentially the same general trend as the 232- and 258-CID economy curves, with lows in economy occuring in 1974 and recoveries occuring in 1975. Automatic transmission equipped vehicles show 1976 decreases in fuel economy, while increases are registered for manual transmission units.

In general, the same comments regarding EGR introduction and relative year-to-year integrated average EGR flow rate levels for the 232- and 258-CID engine apply to the 304-CID engine. However, the 1973 introduction of EGR included all 304-CID engines rather than a single vehicle model as with the smaller engines.

Ignition advance as a function of model year is given in Table 4-6 and in Figures 4-7 and 4-8. These curves exhibit rather substantial differences in advance between vehicles certified to 1974 Federal emission standards as opposed to 1974 California standards, and the differences correlate well with differences in 49-states and California fuel economy curves for 1974. Lower California fuel economy, relative to the 1975/1976 49-states levels, is linked to the continued use of TCS in California vehicles and to the 1975/1976 deletion of TCS in the 49-states vehicles, as explained previously in relation to the 232- and 258-CID engines. Year-to-year use of TCS on the 304-CID engine is detailed in Table 4-3.

One portion of the 304-CID automatic transmission vehicle fuel economy curve of Figure 4-9 is worthy of special comment. The substantial 1974 and 1975 increase is atypical of AMC vehicles. Examination of Table 4-6 emissions data for the 1974 and 1975 model years reveals the reason. In 1974, the single vehicle which contributed the subject 1974 California data point was certified at a NO_x level of 1.2 g/m. As this was considerably lower than the California 2 g/m requirement, AMC was able

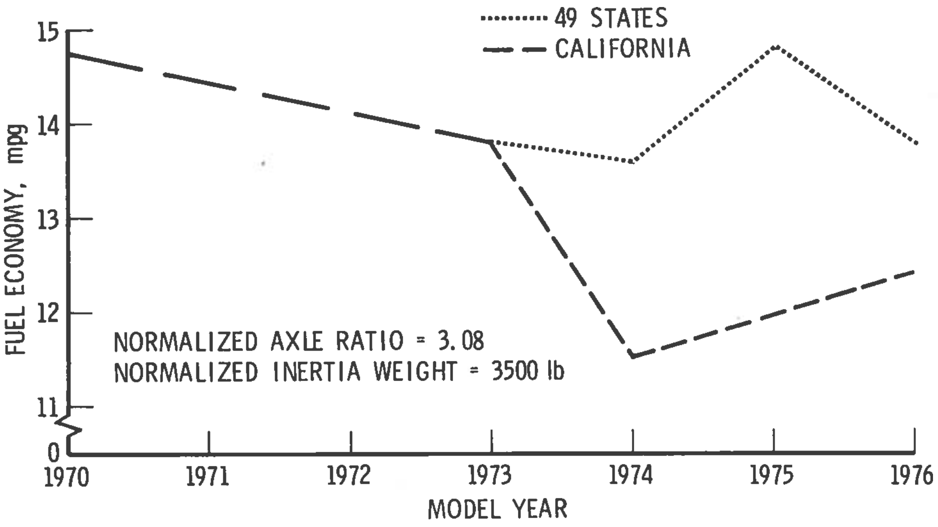


FIGURE 4-9. NORMALIZED AVERAGE CITY FUEL ECONOMY: AMC 304-CID ENGINE WITH AUTOMATIC TRANSMISSION

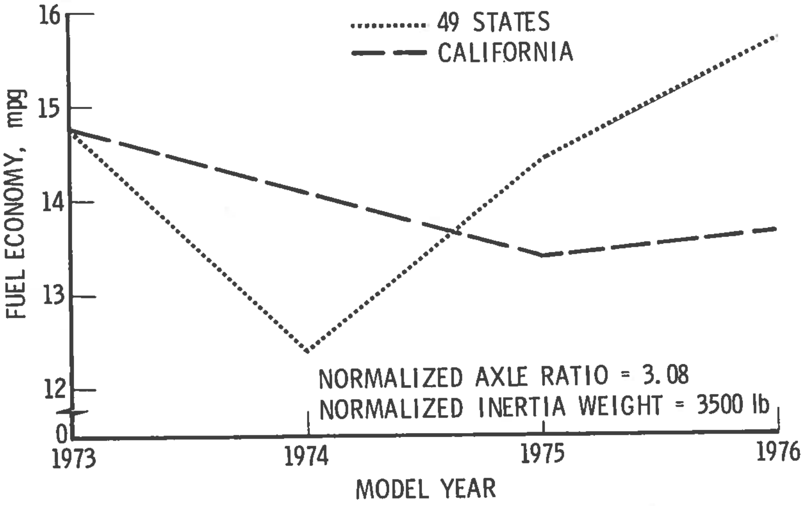


FIGURE 4-10. NORMALIZED AVERAGE CITY FUEL ECONOMY: AMC 304-CID ENGINE WITH MANUAL TRANSMISSION

to recalibrate their exhaust emission control system in 1975 to lessen the margin between statutory and certified NO_x emission levels. This was accomplished, and 1975 versions of the subject engine/transmission combination were certified at 1.9 g/m for NO_x emissions, with an attendant substantial increase in fuel economy. Recalibration was accomplished by increasing the centrifugal ignition advance, as may be seen by referring to Figure 4-7, and by lessening EGR rates slightly as described in the 232- and 258-CID fuel economy discussion.

The 1975 to 1976 decline in fuel economy shown in Figure 4-9 is directly related to the increased 1976 EGR rates and to the centrifugal ignition advance as shown in Figure 4-7 and Table 4-6. As may be seen, in 1976, ignition advance is down from the 1975 levels in the mid-speed ranges used in the Federal Driving Cycle. As expected, the 1976 NO_x emissions are also down relative to 1975 for both 49-states and California vehicles, as shown in Table 4-6.

Small rises in fuel economy from 1975 to 1976 for vehicles with manual transmission, shown in Figure 4-10 are in opposition to decreased year-to-year ignition advance and increased 1976 EGR flow rates. This is an unexplained anomaly, which may be the result of normal vehicle-to-vehicle variations.

Carburetor air/fuel ratios show little variation over recent years as shown in Table 4-6 and have only a second-order impact on fuel economy compared to ignition timing and EGR changes.

4.2 CHRYSLER CORPORATION

4.2.1 Engine/Vehicle Configurations

The Chrysler in-line 6-cylinder 225-CID and V-8 318-CID engines have been selected for evaluation in this study. Since both engines have been in production for more than 10 years, they represent excellent examples for tracing the evolution of the Chrysler engine control practices from essentially uncontrolled configurations to rather sophisticated systems meeting the stringent 1976 Federal and California emission regulations.

In 1976, the 225-CID engine has been used either as standard or optional equipment in a number of vehicles, including the Aspen, Dart, Valiant, Volare, and Fury, covering the range of inertia weights between

3000 and 4500 pounds. In earlier model years, the engine has been a popular powerplant for a number of Dodge and Plymouth cars, including the Belvedere, Coronet, Challenger, Dart, Duster, Fury, Satellite, and Signet. The inertia weight of these vehicles varies between 3500 and 4500 pounds in 1975, 3500 and 4000 pounds in 1974, 3000 and 4000 pounds in 1972, and 3000 and 3500 pounds in 1967.

Currently, the Chrysler 318-CID engine is offered in the Dodge Dart, Charger, and Monaco and in the Plymouth Fury automobiles. The inertia weight of these vehicles varies between 3000 and 4500 pounds. Pre-1976 vehicles incorporating this engine include the Belvedere, Charger, Challenger, Coronet, Cordoba, Dart, Fury, Polara, Satellite, and Valiant. The inertia weight of these vehicles varies between 3500 and 4500 pounds.

4.2.2 Chrysler 225-CID Engine

4.2.2.1 Engine Design Features

Important design parameters and component settings for the Chrysler 225-CID automobile engine are summarized in Table 4-7, covering the time period between 1967 and 1976. While the basic engine remains largely unchanged during this ten-year period, many component design modifications and adjustments have been incorporated by Chrysler to meet the increasingly stringent 49-states and California emission regulations. For example, the 1967 engine is essentially uncontrolled with respect to emissions, except for closed-loop PCV, as described in Section 4.2.2.9, and a simple cleaner air package (CAP) designed to meet the 1966-1969 California emissions standards (3.4 g/m HC and 35 g/m CO, based on the seven-mode test procedure). The CAP system consists of a modified carburetor supplying a leaner air/fuel mixture, a slightly altered distributor, and a sensing valve for the control of spark advance during vehicle deceleration. As shown in Table 4-7, the 1974-1976 model year engines incorporate a number of additional modifications affecting many engine components, including the camshaft, ignition system, carburetor, and exhaust emission control system. These modifications are discussed in the following sections (Refs. 4-23 through 4-32).

TABLE 4-7. ENGINE SPECIFICATIONS: CHRYSLER 225-CID ENGINE

Engine Parameter	Model Year									
	1976		1975		1974		1972		1967	
	49 States	California	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	6		6		6		6		6	
Bore, in.	3.40		3.40		3.40		3.40		3.40	
Stroke, in.	4.125		4.125		4.125		4.125		4.125	
Displacement, cu in.	225		225		225		225		225	
Surface/Volume, 1/in.	6.15		6.15		6.15		6.15		-	
Compression Ratio	8.4		8.4		8.4		8.4		8.4	
Cylinder Head Type	OHV		OHV		OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	100 at 3600	95 at 3600	100 at 3600	95 at 3600	105 at 4000		110 at 4000		145[a] at 4000	
Torque, ft-lb, at Engine Speed, rpm	170 at 1600	165 at 1600	175 at 1600	170 at 1600	185 at 1600		185 at 2000		215[a] at 2400	
Exhaust System Type	Single		Single		Single		Single		Single	
Combustion Chamber Configuration	Wedge		Wedge		Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.62		1.62		1.62		1.62		1.62	
Intake Valve Lift, in.	0.406		0.406		0.406		0.406		0.395	
Exhaust Valve Diameter, in.	1.36		1.36		1.36		1.36		1.36	
Exhaust Valve Lift, in.	0.414		0.414		0.414		0.414		0.395	
Intake Valve Opens, deg BTC	16		16		16		16		10	
Intake Valve Closes, deg ABC	48		48		48		48		50	
Intake Valve Duration, deg	244		244		244		244		240	
Exhaust Valve Opens, deg BBC	54		54		54		54		50	
Exhaust Valve Closes, deg ATC	10		10		10		10		6	
Exhaust Valve Duration, deg	244		244		244		244		236	
Valve Overlap, deg	26		26		26		26		16	
Distributor Type	Breakerless		Breakerless		Breakerless		Breaker point		Breaker point	
Basic Ignition Advance, deg BTC[b]	2-12 (A) 6-12 (M)	2 (A) 4 (M)	0	0	0		0		5	0
Idle Speed, rpm[b]	600 to 750	750 (A) 800 (M)	750	750 (A) 800 (M)	750 (A) 800 (M)		700	750	550	650
Fast Idle Speed, rpm[b]	1700 (A) 1600 (M)	1600	1700 (A) 1600 (M)	1600	1600	1800 (A) 1600 M	2000		-	
Fuel System Type	1-V downdraft Holley 1945		1-V downdraft Holley 1945		1-V downdraft Holley 1945		1-V downdraft Holley 1920		1-V downdraft Holley 1920	
Fuel Metering Method	Fixed orifice		Fixed orifice		Fixed orifice		Fixed orifice		Fixed orifice	
Enrichment Method	Tapered pin power valve		Tapered pin power valve		Tapered pin power valve		2-stage power valve		2-stage power valve	
Choke Type	Automatic electric assist		Automatic electric assist		Automatic electric assist		Automatic		Automatic	
Carburetor Venturi Diameter, in.	1.28		1.28		1.28		1.344	1.250	1.312	
Carburetor Maximum Air Flow, cfm, at Vacuum, in. Hg	167 cfm at 2 in. Hg		167 cfm at 2 in. Hg		167 cfm at 2 in. Hg		149 cfm at 2 in.Hg	137 cfm at 2 in.Hg	-	
Emission Control Systems	CAT EGR EM EVAP PCV	AIR CAT EGR EM EVAP PCV	CAT EGR EM EVAP PCV	AIR CAT EGR EM EVAP PCV	EGR EM EVAP PCV	EGR EM EVAP PCV	EM EVAP PCV	AIR EM EGR EVAP PCV	CAP PCV	
Emission Control Devices	AIC[c] CCEGR Heated air OSAC[c]	CCEGR CCIF[d] EGR timer Heated air OSAC	CAT protection CCEGR CCIE[d] EGR timer Heated air OSAC	CAT protection CCEGR CCIE[d] EGR timer Heated air OSAC	CCEGR Heated air OSAC	CCEGR EGR timer Heated air OSAC	-	AVSAC	-	

[a] Gross rating

[b] A = automatic transmission' M = manual transmission

[c] Some vehicles only

[d] Automatic transmission only

4.2.2.2 Engine Modifications

While the basic wedge-shaped combustion chamber, including the bore, stroke, compression ratio, and surface-to-volume ratio, remained essentially unchanged for the past 10 model years, a number of modifications have been implemented during that time period, primarily to improve the emission characteristics of the engine. These modifications include the use of a larger "quench height" between the piston and cylinder head to prevent flame quenching in this region of the combustion chamber, and a redesigned camshaft providing extended valve overlap.

The increased quench height has resulted in substantially lower HC emissions without compromising fuel economy. As shown in Table 4-7, the modified camshaft has been employed by Chrysler in 1972 and later model year engines. In the new design, intake valve opening has been advanced from 10 to 16 deg before top center (BTC), and exhaust valve closing has been delayed from 6 to 10 deg after top center (ATC). These modifications extend the valve overlap period from 16 to 26 deg causing further dilution of the intake air with combustion gases. This results in lower cylinder peak temperatures and NO_x formation rates. In 1972, induction-hardened valves were introduced in the Chrysler 6-cylinder engine families to permit operation on lead-free gasoline.

4.2.2.3 Air Intake System

All 1971 and later model year 225-CID engines are equipped with a heated intake air system which is designed to provide near constant carburetor intake air temperatures for all engine operating conditions, except full load. The objective of the system is to accelerate the fuel vaporization process in the intake manifold, providing a more uniform air/fuel mixture and permitting the use of leaner carburetor calibrations for improved HC emission control and vehicle driveability.

The heated air system consists of a stove surrounding the exhaust manifold, a flexible connector between the stove and the air cleaner, and a control valve located in the snorkel of the air cleaner. For underhood air temperatures below $65^{\circ}F$ (1976 model year), $80^{\circ}F$ (1975 model year), or $90^{\circ}F$ (1974 model year), the intake air is drawn through the stove.

Conversely, for temperatures above 95°F (1976), 110°F (1975), or 120°F (1974), the valve is closed, and the intake air enters directly through the snorkel. At intermediate temperatures, air is inducted through both circuits. Modulation of the intake air temperature is accomplished by a temperature sensor and an intake manifold vacuum controlled diaphragm operating the air control valve. The vacuum diaphragm is opposed by a spring, and therefore temperature modulation takes place only under road-load conditions or when the manifold vacuum is above the operating vacuum of the diaphragm. For faster warmup and improved driveability after cold starts, an exhaust manifold heat control valve has been in use since 1967. This valve, which is thermostatically controlled, directs heated exhaust gases to a heat chamber located in the intake manifold beneath the carburetor to enhance fuel vaporization during engine warmup. This permits leaner air-fuel mixture operation of the engine during warmup, resulting in lower HC and CO emissions. The wall thickness of the intake manifold has been reduced over the years to improve the transfer of heat from the exhaust gases into the intake air.

4.2.2.4 Carburetor

4.2.2.4.1 Design Features

For the past ten model years, the 225-CID engine has been equipped with a Holley single-venturi, concentric downdraft carburetor. While the basic carburetor design has remained unchanged during this time, a number of significant modifications have been incorporated, including the resizing of the venturi diameter and main metering jet and the application of improved idle and choke systems, as well as improved manufacturing precision. These modifications are aimed at achieving improved fuel metering and better mixture distribution to permit leaner engine operation resulting in lower HC and CO emissions and improved fuel economy.

The Holley carburetor has five basic metering systems: the idle system, main metering system, power enrichment system, accelerator pump system, and choke. These flow circuits are briefly described in the following paragraphs.

The idle system, exemplified by the 1974 configuration shown in Figure 4-11, is designed to provide a rich mixture for smooth idle and off-idle operation. At idle, fuel flows from the main metering jet through the idle tube and mixes with the air entering the system through the idle air bleed. Additional air enters through the idle transfer slot located just above the throttle to assist in the breakup of the fuel droplets. As the throttle plate is partially opened during low-load operation of the engine, the flow field in the vicinity of the transfer slot changes, causing fuel to be discharged through both the transfer slot and the idle port.

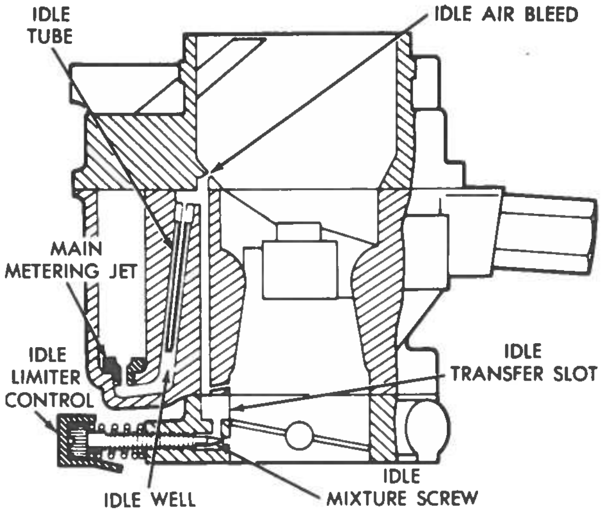


FIGURE 4-11. IDLE SYSTEM: 1974 CHRYSLER 225-CID ENGINE

With increasing engine load, the air flow increases, creating a vacuum in the venturi section of the carburetor and forcing fuel to flow through the main jet into the main well. As shown in Figure 4-12, air entering the main well through the high-speed air bleed mixes with the fuel and assists in the fuel vaporization process. Since the fuel-air mixture is lighter than fuel, the response of the system is improved relative to fuel-only configurations.

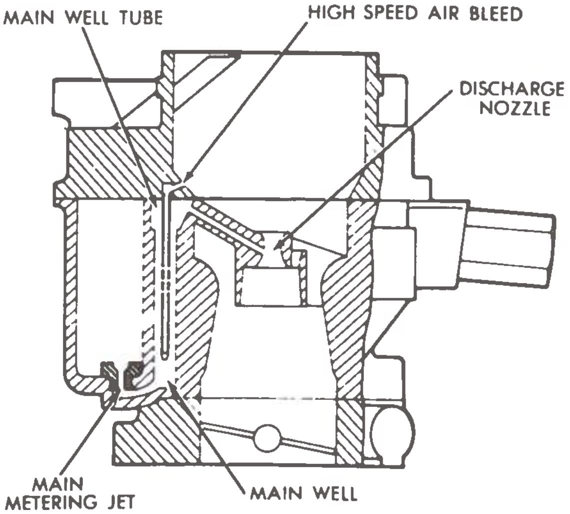


FIGURE 4-12. MAIN CARBURETOR METERING SYSTEM: 1974 CHRYSLER 225-CID ENGINE

The power enrichment system is designed to provide additional fuel near full-load operation of the engine. This system consists of a power valve and a vacuum piston. In the case of high manifold vacuum (light load), the vacuum piston is pushed to the top of the cylinder, and the spring is compressed. As manifold pressure declines to a predetermined level, the spring overcomes the vacuum, and the piston stem forces the needle of the power valve into the open position, permitting additional fuel flow into the carburetor well. The system used in the 1974 California vehicles and in all 1975 and 1976 model 49-states and California vehicles includes a mechanical modulator rod which is designed to fully open the power valve when the throttle approaches its wide-open position, regardless of engine vacuum.

While the carburetor responds almost instantaneously to sudden changes in the throttle position, there is a small lag before the fuel can overcome its inertia and maintain the desired air/fuel ratio. In current carburetor designs, this deficiency is overcome by means of an accelerator pump system of the type shown in Figure 4-13. In this configuration, fuel enters the pump cylinder from the fuel bowl. As the throttle lever is moved, the pump link, operating through a system of levers and a pump drive spring, pushes the pump piston down and forces fuel out through the pump discharge jet.

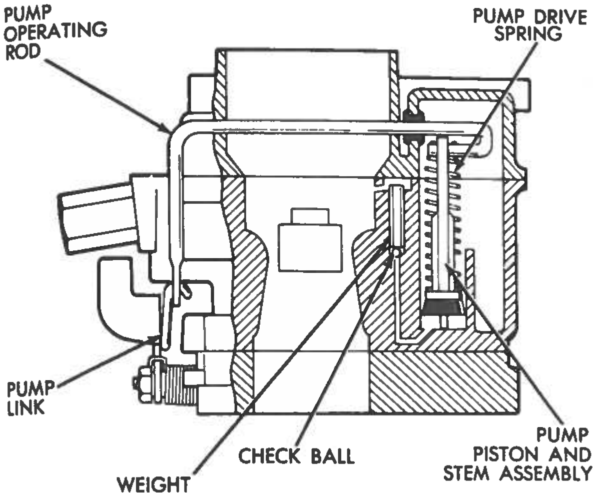


FIGURE 4-13. ACCELERATOR PUMP SYSTEM: 1974 CHRYSLER 225-CID ENGINE

4.2.2.4.2 Cold Start Control

All 225-CID Chrysler engines are equipped with an automatic choke and vacuum kick diaphragm to provide a rich fuel/air mixture during engine starting and warmup. A bimetallic spring located inside the choke housing pushes the choke valve into the closed position. As the engine warms up, manifold heat transmitted to the choke housing relaxes the bimetallic spring until the choke is fully open. Immediately after a successful engine start, the vacuum kick diaphragm opens the choke by a predetermined small amount to prevent engine stalling caused by over-rich mixtures. In 1973, an electric assist unit was included in the choke housing to assist in the warm-up of the bimetallic spring. This reduces the choke action time, resulting in lower HC and CO emissions during engine warmup. The choke control unit consists of two bimetallic switches located on the engine adjacent to the choke well. One switch provides power to the electric heating elements for temperatures of 60°F and above. The second switch, installed in series with the first has its own heating coil, which heats its bimetallic spring and opens the circuit after a predetermined time of about 2-4 minutes. The heater is shut off when the control switch temperature reaches 130°F.

To assure reliable engine starting and operation immediately after starting, a coolant-controlled idle enrichment system (CCIE) is used in the automatic transmission equipped 1975 model 49-states vehicles and in the 1975 and 1976 California vehicles with automatic transmission. This system consists of an electronic timer and a vacuum solenoid valve. The timer energizes the solenoid during engine starting and for a period of 35 seconds thereafter. When energized, the solenoid applies manifold vacuum to the idle enrichment system via a block coolant valve which initiates idle enrichment when the engine block temperature is below 150°F. The system used in 1976 employs a three-way vacuum solenoid valve instead of the two-way valve used in 1975. In addition to the idle enrichment function, this valve interrupts the vacuum supply to the EGR valve, hence eliminating EGR during the initial warmup period of the engine for the purpose of achieving better vehicle driveability.

As shown in Table 4-7, the curb idle and fast idle speeds of the 1972-1976 model year engines are considerably above the 1967 levels. These adjustments were implemented as a means of reducing the relatively high HC and CO emissions generally obtained during warmup and preventing engine stalling following a cold start. Both modifications are accompanied by small losses in fuel economy.

4.2.2.4.3 Carburetor Calibration

Typical Chrysler carburetor calibration curves, exemplified by the 1975 model year 49-states and California engines with automatic transmission, are presented in Figure 4-14. The two upper curves represent part-load conditions, while the lower curves are for WOT. In the part-load regime, the carburetor provides a lean mixture except for very low flow rates. Conversely, at full load, the mixture is enriched, resulting in air/fuel ratios between near-stoichiometric and about 10 percent rich. Richer mixtures are employed in the California vehicles, along with spark timing and EGR system modifications to meet the more stringent California emission regulations.

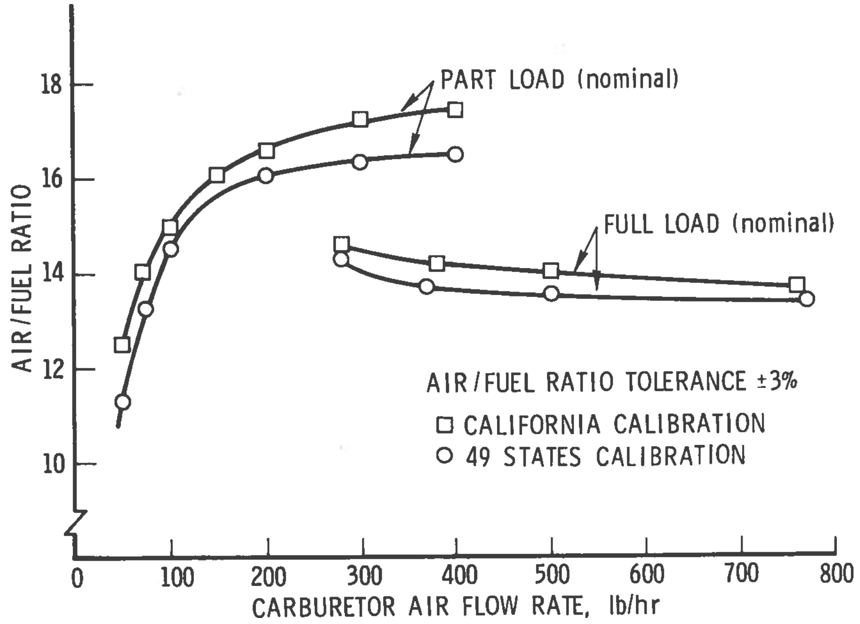


FIGURE 4-14. CARBURETOR CALIBRATION: 1975 CHRYSLER 225-CID ENGINE WITH AUTOMATIC TRANSMISSION

The carburetor calibration data for the 1974 through 1976 model year certification vehicles with automatic and manual transmission are listed in Tables 4-8 and 4-9, respectively, showing the mean air/fuel ratio at four discrete air flow settings. While the air/fuel ratio tolerance band has remained near ±3 percent for the past several years, Chrysler has improved the manufacturing precision of the carburetor during that time period, resulting in smaller hardware-to-hardware air/fuel ratio excursions within the tolerance band.

TABLE 4-8. CERTIFICATION CALIBRATION DATA: CHRYSLER 225-CID ENGINE WITH AUTOMATIC TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard																					
	1976 49 States				1976 California			1975 49 States					1975 California			1974 49 States		1974 Calif	'72 49 States	1972 Calif	1970	1967
Vehicle Model	P^a	Da^b	D^f	D^c	V^d	V^d	F^e	P^a	D^c	P^a	D^c	D^c	D^c	P^a	Da^b	Da^b	P^a	P^a	P^a	P^a	DP^g	DP^g
Vehicle Identification No.	4084	4060	4055	4055	4175	4152	4154	2087	2088	2098	2136	2141	2151	2154	2196	-	-	-	-	-	-	-
Vehicle Inertia Weight, lb	3000	3500	4000	4500	3500	3500	4000	3500	3500	4500	4500	4000	4000	3500	4000	3500	3500	3500	-	-	-	-
Rear Axle Ratio	2.76	2.76	3.21	3.21	2.94	3.23	3.23	2.76	2.45	3.21	2.94	3.23	2.45	2.76	3.23	2.76	2.76	-	-	-	-	-
Catalyst	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
Air Conditioning	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Carburetor Calibration, A/F																						
Idle: 45-lb/hr air flow	13.0	12.7	12.7	12.7	11.5	11.5	11.5	12.5	12.4	12.5	12.5	12.4	11.3	11.5	11.3	13.4	13.4	13.4	-	-	-	-
Off-Idle: 105-lb/hr air flow	15.3	15.2	15.2	15.2	14.3	14.2	14.9	15.0	15.4	15.0	15.0	15.4	14.9	14.9	14.3	16.0	16.0	16.0	15.6	15.6	15.4	-
Part Throttle: 200-400 lb/hr air flow	16.4	17.0	17.0	17.0	16.2	16.2	16.2	17.2	17.0	17.3	17.3	17.0	16.4	16.4	16.4	16.4	16.4	16.5	16.1	16.1	16.1	-
WOT at Max.: 800-lb/hr air flow	14.0	13.7	13.7	13.7	13.1	13.7	13.1	13.7	13.7	14.8	14.8	13.7	13.5	13.1	13.4	13.2	13.2	13.3	-	-	-	-
Basic Timing, crankshaft deg BTC	12	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Centrifugal Advance, crankshaft deg																						
1000 rpm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	2	2	0	3.5	3
1200 rpm	1.5	5.5	5.5	5.5	6	6	6	5.5	5.5	5.5	5.5	5.5	5	5.5	5	7.5	7.5	5.5	7.5	0	8.5	6
1500 rpm	5	14	14	14	14.5	14.5	15	14	14	14	14	14	13.5	13	13	15	15	11	15	6	16	11
2000 rpm	6	16	16	16	16	16	16	19	19	19	19	19	19	18.5	19	21	21	17	21	15	21	17
3000 rpm	7	18	18	18	18	18	18	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	23.5	23.5	21.5	23.5	21	23.5	20
4000 rpm	8	20	20	20	19.5	19.5	19.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	26	26	26	26	24.5	26	22
5000 rpm	9.5	20.5	20.5	20.5	21.5	21	20	24	24	24	24	24	26	25	25	25	25	25	26	26	26	23
Vacuum Advance, crankshaft deg																						
5 in. Hg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 in. Hg	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0
7 in. Hg	9.5	3.5	3.5	3.5	2.5	3	2.5	3.5	3.5	3.5	3.5	3.5	3	3.5	2.5	3	3	3	3.5	3.5	4	2
8 in. Hg	18	7	7	7	6	7	7	6.5	6.5	6.5	6.5	6.5	6.5	7	6	6.5	6.5	7	7.5	7.5	7.5	4
10 in. Hg	22	13.5	13.5	13.5	13	14	14.5	13.5	13.5	13.5	13.5	13.5	14	14	14	13.5	13.5	13.5	13	13	13	12
12 in. Hg	22	17	17	17	16	17	17	17	17	17	17	17	16.5	17	16.5	17	17	17	13	13	13	12
14 in. Hg	22	17	17	17	16	17	17	17	17	17	17	17	16.5	17	16.5	17	17	17	13	13	13	13
16 in. Hg	22	17	17	17	16	17	17	17	17	17	17	17	16.5	17	16.5	17	17	17	13	13	13	13
EGR Valve Calibration Flow, lb/hr																						
5-in. Hg	65	53	53	53	71	71	75	53	53	53	53	53	99	100	92	53	53	95	0	Some	0	0
9-in. Hg	75	74	74	74	115	115	111	73	73	73	73	73	145	144	143	73	73	165	0	Some	0	0
Fuel Economy, mpg																						
City	23	18	17	16	15	14	13	18	18	14	14	16	15	15	14	16.7^h	16.7^h	-	-	-	-	-
Highway	30	23	22	23	21	19	17	23	24	24	20	23	19	20	19	-	-	-	-	-	-	-
Exhaust Emissions, g/m																						
HC	0.4	1.0	0.8	0.8	0.6	0.7	0.7	0.6	0.7	0.6	0.7	1.0	0.7	0.7	0.7	2.3^h	2.2^h	-	-	-	-	-
CO	5	9	6	7	5	5	9	3	4	6	9	7	8.6	4.8	5.4	31^h	23^h	-	-	-	-	-
NO_x	2.7	2.3	2.4	2.9	1.4	1.1	1.0	2.7	2.3	2.9	2.7	2.6	2.0	1.4	1.7	2.9^h	2.8^h					

[a] Plymouth
[b] Dart
[c] Dodge
[d] Valiant
[e] Fury
[f] Dodge
[g] Dodge; Plymouth
[h] 1972 FTP

TABLE 4-9. CERTIFICATION CALIBRATION DATA: CHRYSLER 225-CID ENGINE WITH MANUAL TRANSMISSION

Engine / Vehicle Parameter	Model Year and Certification Standard														
	1976 49 States				1976 California		1975 California		'74 49 States	1974 California		'72 49 States	1972 Calif	1970	1967
Vehicle Model	V[a]	V[a]	P[b]	P[b]	Da[c]	F[d]	P[b]	Da[c]	P[b]	D[e]	D[e]	DP[f]	DP[f]	DP[f]	DP[f]
Vehicle Identification No.	4085	4093	4063	4068	4155	4182	2052	2198	-	-	-	-	-	-	-
Vehicle Inertia Weight, lb	3000	3000	3500	4000	3500	4000	3500	4000	-	4000	4000	-	-	-	-
Rear Axle Ratio	2.94	2.94	3.23	2.94	3.23	3.21	2.71	3.23	-	3.91	3.91	-	-	-	-
Catalyst	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
Air Conditioning	No	No	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Carburetor Calibration, A / F															
45-lb / hr air flow	13.0	13.0	13.3	13.3	12.2	12.2	11.4	11.5	12.5	12.5	12.5	-	-	-	-
105-lb / hr air flow	15.2	15.2	16.3	16.3	15.8	15.8	15.4	15.5	15.1	15.3	15.3	-	-	15.2	-
200-400 lb / hr air flow	16.4	16.4	17.0	17.0	16.8	16.8	17.0	17.0	16.5	16.7	16.7	-	-	15.6	-
WOT: 800-lb / hr air flow	14.0	14.0	14.0	14.0	13.8	13.9	14.0	14.3	13.2	13.2	13.2	-	-	-	-
BASIC TIMING, crankshaft deg BTC	12	12	6	6	4	4	0	0	0	0	0	0	0	0	5
Centrifugal Advance, crankshaft deg															
1000 rpm	0	0	0	0	2.5	2.5	0	0	2.5	0	0	2	0	3.5	3
1200 rpm	1.5	1.5	8	8	8	8	5	6	7.5	2	2	7.5	0	8	6
1500 rpm	5	5	10.5	10.5	11	11	13	13.5	15	8	8	15	6	16	11
2000 rpm	6	6	11.5	11.5	12	11.5	19	19.5	21	15	15	21	15	21	17
3000 rpm	7	7	13	13	12.5	13	22	22	23.5	20.5	20.5	23.5	21	23.5	19.5
4000 rpm	8	8	14.5	14.5	13.5	14.5	24.5	24	26	26	26	26	24.5	26	22
5000 rpm	9.5	9.5	16	16	15	16	25	25	25	25	25	26	26	26	23
Vacuum Advance, crankshaft deg															
5 in. Hg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 in. Hg	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
7 in. Hg	9.5	9.5	3.5	3.5	3	3	3	3	1	1	1	3.5	3.5	0	0
8 in. Hg	18	18	7	7	7	7	6.5	7	2.5	2.5	2.5	7.5	7.5	1	1
10 in. Hg	22	22	13.5	13.5	14.5	13.5	13	13.5	5	5	5	13	13	4	3.5
12 in. Hg	22	22	17	17	16.5	17	17	16	9.5	9.5	9.5	13	13	8	7
14 in. Hg	22	22	17	17	16.5	17	17	16	14.5	14.5	14.5	13	13	12	11
EGR Valve Calibration Flow, lb / hr															
Flow At 5-in. Hg	65	65	35	35	53	53	75	70	31	58	58	0	Some	0	0
Flow At 9-in. Hg	75	75	46	46	74	74	114	115	43	74	74	0	Some	0	0
Fuel Economy, mpg															
City	22	23	18	18	16	17	16	15	0	12.1[g]	11.5[g]	-	-	-	-
Highway	31	35	25	30	23	24	24	20	-	-	-	–	-	-	-
Exhaust Emission, g / m															
HC	1.0	0.7	0.9	1.2	0.9	0.7	0.7	0.9	-	2.9[g]	2.8[g]	-	-	-	-
CO	15	15	10	13	5	4	7	6	-	37[g]	35[g]	-	-	-	-
NO_x	1.9	2.5	2.2	2.9	1.5	1.6	1.5	1.8	-	2.0[g]	1.6[g]	-	-	-	-

[a] Valiant

[b] Plymouth

[c] Dart

[d] Fury

[e] Dodge

[f] Dodge; Plymouth

[g] 1972 FTP

In general, the calibration modifications implemented by Chrysler since 1974 are small. At low flow rates, the air/fuel ratio of the 49-states vehicles with automatic transmission (Table 4-8) was reduced by about 5 percent between 1974 and 1975, followed by very slight increases in 1976. Conversely, in the part-load regime and at WOT, the mixture was leaned out between 1974 and 1975, followed by slightly lower air/fuel ratios in 1976. Similar trends are observed for the California vehicles and the vehicles with manual transmission (Table 4-9).

Although not shown, the carburetor was leaned out between 1967 and 1972, primarily to meet the HC and CO emission regulations commencing in 1967 in California and nationwide in 1968.

4.2.2.5 Ignition System

4.2.2.5.1 Design Features

All pre-1972 Chrysler 225-CID engines are equipped with a conventional ignition system consisting of the ignition coil, distributor, breaker points, condenser, and rotor. Electronic ignition, which had been introduced by Chrysler in 1972 in some engine families, has been used exclusively in 1973 and later model year engines. The principal feature of electronic ignition relative to conventional systems is the elimination of the breaker points, which are replaced by a magnetic arrangement to trigger delivery of electric energy to the spark plugs. As a result, engine misfiring, accompanied by higher exhaust emissions and periodic system maintenance and replacement of parts, has been eliminated. Additional advantages of the electronic system include the supply of a higher and more uniform voltage to the spark plugs and more precise spark timing, resulting in improved combustion, fuel economy, and emission characteristics.

The Chrysler electronic ignition system, shown schematically in Figure 4-15, is of the inductive type and is composed of a conventional ignition coil, a control unit between the distributor and the coil, and a dual ballast resistor. The distributor incorporates a toothed reluctor wheel, driven by the crankshaft, and a magnetic pickup in place of the cam and breaker points used in conventional distributors. The control unit includes a power switching transistor which opens and closes the primary circuit of the ignition coil, as well as other electronic circuitry controlling the power switching transistor.

The magnetic pickup unit has a permanent magnet which is used to induce a voltage in the pickup coil and a reluctor wheel which varies the magnetic flux generated by the magnet and acts as a bridge for the flux between the magnet and the pickup coil. When a reluctor tooth passes the pole piece of the magnet, the magnetic flux in the pickup coil is varied, inducing a voltage across the pickup coil terminals. This triggers the control unit which causes the power switching transistor to interrupt the primary circuit of the ignition coil. As a result, a high voltage is induced in the secondary windings of the coil, which fires the spark plugs. Since the pole piece and the reluctor teeth are separated by a small air gap, there is no wear on this unit.

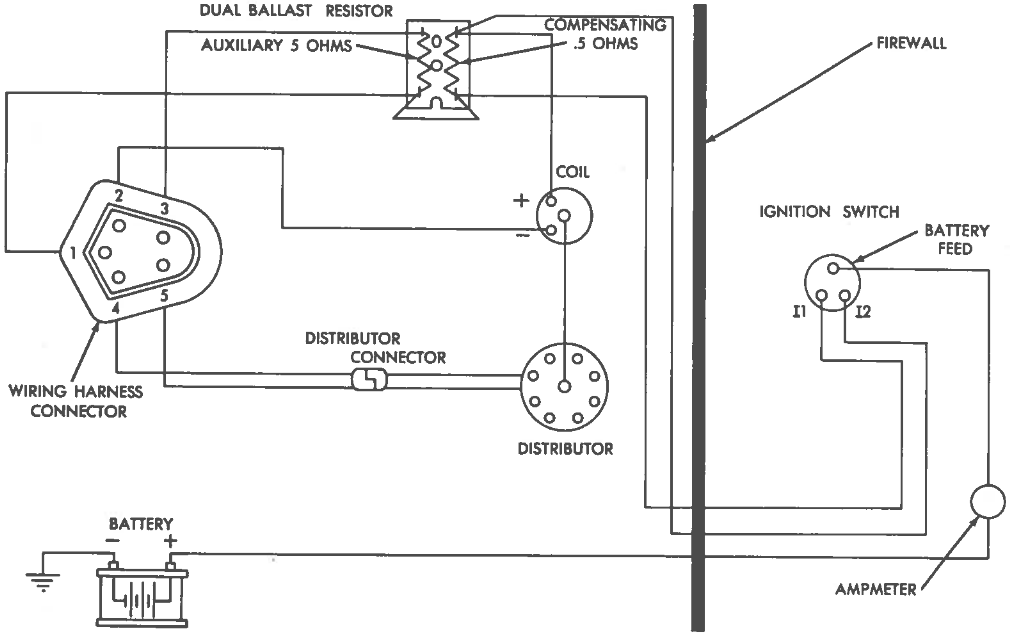


FIGURE 4-15. CHRYSLER ELECTRONIC IGNITION SYSTEM SCHEMATIC

The normal side of the dual ballast resistor assumes the function of the ballast resistor used in the Chrysler breaker-point ignition systems. It is designed to protect the ignition coil from excessive voltage during low-speed operation of the engine by reducing the voltage to the primary side of the coil. As speed increases, the duration of the current flowing through the ballast resistor is reduced. As a result, the resistor temperature and its resistance decrease raising the voltage to the ignition coil. The auxiliary side of the ballast resistor is used to protect the control unit by limiting the voltage to the electronic circuitry of the primary circuit.

4.2.2.5.2 Spark Timing Control Devices

For maximum performance and emission control, spark timing must be correctly adjusted for all engine operating conditions to account for differences in the flame speed resulting from changes in engine operating speed, pressure, air/fuel ratio, and EGR flow rate. This is accomplished by means of centrifugal and vacuum distributor mechanisms. While the simple flyweight and vacuum diaphragm techniques are still used in most current ignition systems, a number of additional controls has been added during the past few years to assist in the overall emission control of the engine.

The 1972 model vehicles marketed in California incorporate a spark retard system for NO_x control. The system utilized in conjunction with a manual transmission consists of two components: a transmission switch and a solenoid vacuum valve. The transmission switch senses the gear selection and opens when the top gear is engaged. The solenoid vacuum valve incorporates a plunger which, when energized, disconnects the vacuum line from the carburetor to the distributor and deactivates the vacuum advance in the low gears, providing additional NO_x control in these modes of operation. A different system, composed of a speed switch, control unit, and solenoid vacuum valve, is employed in the vehicles with automatic transmission. The speed switch senses vehicle speed, and the control unit senses ambient temperature. The solenoid vacuum valve is identical to that used with manual transmission. Below ambient temperatures of 70°F and vehicle speeds of 30 mph, the solenoid is energized, and the vacuum spark advance mechanism is deactivated.

Starting with model year 1973, all 225-CID engines incorporate the Chrysler orifice spark advance control (OSAC) valve, which is designed to assist in the control of NO_x and HC emissions. The valve delays the onset of vacuum spark advance during vehicle acceleration by restricting the flow of air from the distributor vacuum advance chamber to the carburetor vacuum port for about 17 seconds in the 49-states vehicles and 28 seconds in the California vehicles. The restriction is only in one direction, and there is no delay in retarding the spark during closed throttle deceleration or WOT acceleration, when the carburetor port vacuum drops below the vacuum level in the vacuum advance chamber. The OSAC valve, located in the air cleaner contains a thermal control device to retain reliable driveability during engine warmup. The device consists of a bimetallic disc which opens the OSAC valve for intake air temperatures below 58°F. In this case, the vacuum line to the advance chamber is unrestricted in both directions until the control temperature is reached.

In 1976, Chrysler introduced its electronic spark advance system (ESA). While the use of ESA is currently limited to the 49-states 400-CID engine, which is not treated in this study, the system is briefly described because of its capability of providing improved spark control over a wider range of operating conditions and its potential application to other engine families in the near future. As a result of better spark control, the HC and NO_x emissions are reduced relative to conventional advance mechanisms. In the ESA system, spark timing is modulated as a function of several operating parameters, including speed, manifold vacuum, throttle position, rate of throttle position change, inlet air temperature, and coolant temperature. When a reluctor tooth passes the pickup coil, the voltage in the pickup circuit is set to zero. The voltage then builds up at a variable rate, reaching a maximum just as the next tooth passes the coil. This voltage is continuously compared to a reference voltage. When both voltage levels are equal, the spark plug is fired. The reference voltage is lowered to advance the spark, based on the measurement of the various parameters noted.

4.2.2.5.3 Centrifugal and Vacuum Advance Schedules

Typical Chrysler centrifugal and vacuum advance schedules, exemplified by the 1975 model 225-CID California and 49-states vehicles with automatic or manual transmission, are presented in Figure 4-16. The centrifugal advance commences at about 1000 rpm and increases rapidly to 18 crankshaft degrees at 1650 rpm. Between 1650 and 4400 rpm, the spark advance increases more gradually, followed by a slight decline above 4400 rpm.

The vacuum advance starts at about a 6-in. -mercury (Hg) vacuum and increases rapidly to about 17 crankshaft degrees at 11-in. -Hg vacuum and at higher vacuum levels. While the tolerance specification for both centrifugal and vacuum advance has remained nearly constant since 1967, Chrysler has reduced the distributor production tolerances during the past several years to assist in the control of HC and CO by providing more precise spark timing control for all engine operating conditions.

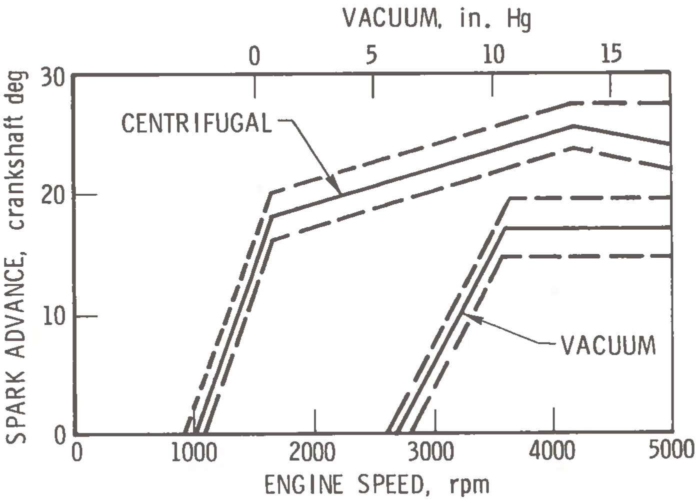


FIGURE 4-16. SPARK ADVANCE SCHEDULE: 1975 CHRYSLER 225-CID ENGINE WITH AUTOMATIC OR MANUAL TRANSMISSION; 49-STATES AND CALIFORNIA CALIBRATIONS

The centrifugal and vacuum advance schedules of the 1972 and 1974-1976 certification vehicles and of selected 1967 and 1970 in-use vehicles are presented in Tables 4-8 and 4-9 for automatic and manual transmissions, respectively. The 1972 and 1974-1976 data have been extracted from the respective application for certification documents (Refs. 4-23 through 4-29), whereas the 1967 and 1970 data have been obtained from the Ethyl Corporation (Refs. 4-33 and 4-34). In the discussion of the effects of spark timing on fuel economy, the centrifugal advance of the 49-states vehicles with automatic transmission including basic timing is plotted in Figure 4-17, showing spark advance in terms of crank degrees as a function of engine speed and model year. With the advent of HC and CO emission regulations in 1968, the centrifugal advance was reduced in the low-speed regime, relative to 1967, but remained nearly constant at higher speeds (Ref. 4-35). Between 1968 and 1974, the centrifugal advance changed very little and declined moderately in 1975 and 1976, except for a small increase in 1976 at 1500 rpm.

The centrifugal spark advance of the 1967-1970 California vehicles with automatic transmission is identical to the 49-states settings (Refs. 4-33 through 4-35). However, with the advent of NO_x control in California in 1971, followed by more stringent NO_x standards in 1972, the centrifugal advance of the California vehicles in the low-speed regime was reduced relative to the 49-states settings. For example, at 1500 rpm, the centrifugal advance of the California vehicles is only 6 deg, compared with 15 deg for the 49-states calibration (Table 4-8). Similar trends are observed in Table 4-8 for the 1974 model year, when the California NO_x standard was reduced to 2.0 g/m, whereas the 49-states standard remained at the 1973 level of 3.0 g/m. In subsequent years, the centrifugal advance of the California vehicles was restored, and the burden of NO_x control was shifted to the EGR system.

The vacuum advance of the 1967-1976 model 49-states vehicles with automatic transmission is depicted in Figure 4-18, as a function of distributor vacuum. Again, the spark advance remained nearly constant between 1967 and 1975, except for a small increase implemented in 1974 and 1975 at 12-in.-Hg vacuum and above, followed by a significant increase in 1976. The 1976 data shown in Figure 4-18 represent the 3000 pound certification vehicle (Table 4-8), which utilizes higher vacuum advance than the other 1976 vehicles shown in the table. The impact of the increased spark advance on vehicle fuel economy is discussed in Section 4.2.2.10.

In the main, the spark advance schedules of the vehicles with manual transmission are similar to the settings used in the automatic transmission equipped vehicles, except for 1974. In this case, Chrysler has employed lower vacuum advance with the manual transmission to provide adequate NO_x control in conjunction with lower EGR rates.

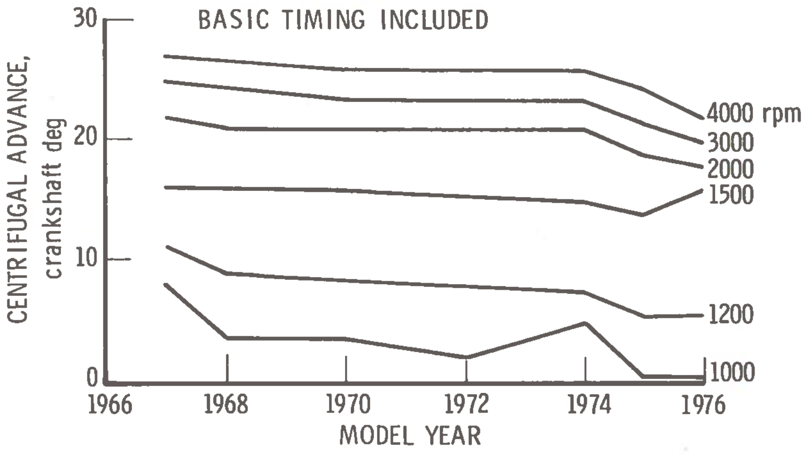


FIGURE 4-17. CENTRIFUGAL ADVANCE SCHEDULE: CHRYSLER 225-CID ENGINE WITH AUTOMATIC TRANSMISSION; 49-STATES CALIBRATION

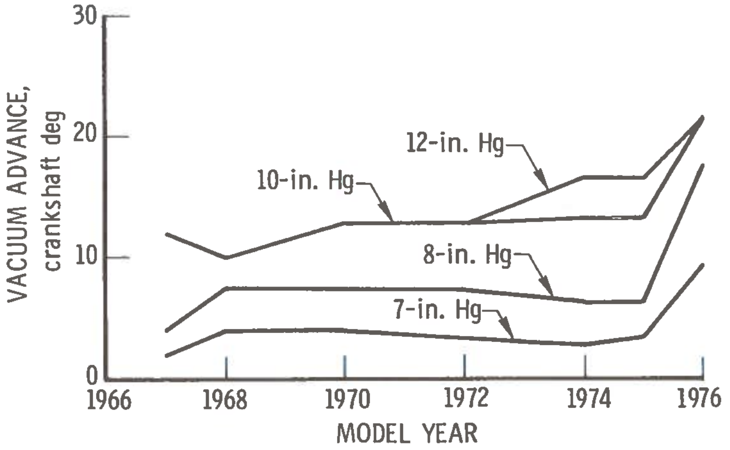


FIGURE 4-18. VACUUM ADVANCE SCHEDULE: CHRYSLER 225-CID ENGINE WITH AUTOMATIC TRANSMISSION; 49-STATES CALIBRATION

The distributor vacuum is generally provided by a carburetor vacuum port, except for the 1976 model 49-states vehicles, which incorporate a manifold vacuum source. While the manifold vacuum system increases the spark advance at idle and accelerates the advance buildup in the very low load regime, the characteristics of the two control systems are similar for most other engine operating conditions.

4.2.2.6 Exhaust Gas Recirculation

4.2.2.6.1 Design Features

EGR was introduced in the 1972 California vehicles as a means of assisting in the control of NO_x, in conjunction with spark advance control and extended camshaft overlap. In the 1972 system, the exhaust gases are taken from the exhaust manifold plenum chamber located at the "hot spot" below the carburetor heat riser. The EGR flow is circulated by means of an orifice which permits a controlled amount of exhaust gas into the intake manifold to dilute the fuel/air mixture.

A more sophisticated EGR system has been employed since 1973, consisting of an EGR valve and a venturi vacuum control unit. The EGR valve is a vacuum diaphragm poppet-type design which circulates the exhaust gas flow from the exhaust crossover in response to a vacuum signal originating at the throat of the carburetor venturi. Because of the low signal strength, a vacuum amplifier is used which increases the signal strength to the level required to operate the valve. The amplifier uses stored manifold vacuum from an internal reservoir to provide the source of amplification. In most installations, EGR is eliminated at WOT by means of a dump diaphragm, which determines the WOT point by comparing the venturi and manifold vacuum levels. At WOT, the internal reservoir is dumped and manifold vacuum, which is low under these conditions, is applied to the EGR valve. Since the opening point of this valve is set above the manifold vacuum corresponding to WOT, the valve is then closed, and no EGR flow is admitted to the engine.

As shown in Table 4-7, all 1974-1976 engines are equipped with a coolant-controlled EGR (CCEGR) system and an EGR time delay unit, except for the 1974 and 1976 model 49-states configurations which are calibrated without the EGR timer. The objectives of these two devices are to improve vehicle driveability when the engine is cold and to reduce the cold start HC emissions. The CCEGR system consists of an engine coolant temperature-controlled valve, located in the radiator top tank, which eliminates EGR during a cold start by interrupting the vacuum supply to the EGR flow valve. In general, the CCEGR valve opens when the coolant temperature reaches about 70°F, except in the case of the 1976 model 49-states engine which has no EGR below coolant temperatures of about 120°F. The EGR time delay unit, which consists of an electronic timer and a solenoid valve, is designed to delay the flow of EGR by about 35 seconds after engine start. The system functions under all starting conditions, including restarts.

4.2.2.6.2 EGR Valve Calibration

EGR valve calibration data for the 1974-1976 certification vehicles are listed in Tables 4-8 and 4-9, showing the mean air flow rates through the valve, corrected to standard conditions, for two vacuum settings (5-in. Hg and 9-in. Hg). In general, higher EGR rates are employed in the California vehicles, reflecting the more stringent California standards. With the exception of the 1976 model 49-states calibrations, the vehicles with manual transmission have less EGR because of the higher efficiency of the manual transmission, particularly in the low-load regime of the Federal Driving Cycle, resulting in lower engine power requirements and lower NO_x formation rates.

The operational characteristics of the EGR system used in the 1974 model 49-states vehicles with automatic transmission are illustrated in Figure 4-19 (Ref. 4-31). The top curve shows the EGR flow, expressed as a percentage of engine flow, as a function of engine road load rpm. This calibration curve, which is typical of all Chrysler EGR systems, shows zero EGR at engine road load speeds below 1200 rpm. With increasing speed, the EGR rate increases rapidly and reaches a maximum at about 2000 rpm, followed by a gradual decline in the high-speed regime. The bottom portion of the figure shows the EGR flow rate as a function of signal vacuum (engine load) and engine rpm. For each engine speed, the EGR flow rate is zero at high and low signal pressures (corresponding to high and low engine loads) with high EGR rates occurring at intermediate vacuum levels. It is obvious that the system is by no means a proportional system, but one that is designed to meet the emission regulations consistent with acceptable driveability and fuel economy characteristics. The performance of the Chrysler 1975 EGR system under the transient operating conditions of the Federal Driving Cycle are discussed in Section 4.2.3.6.

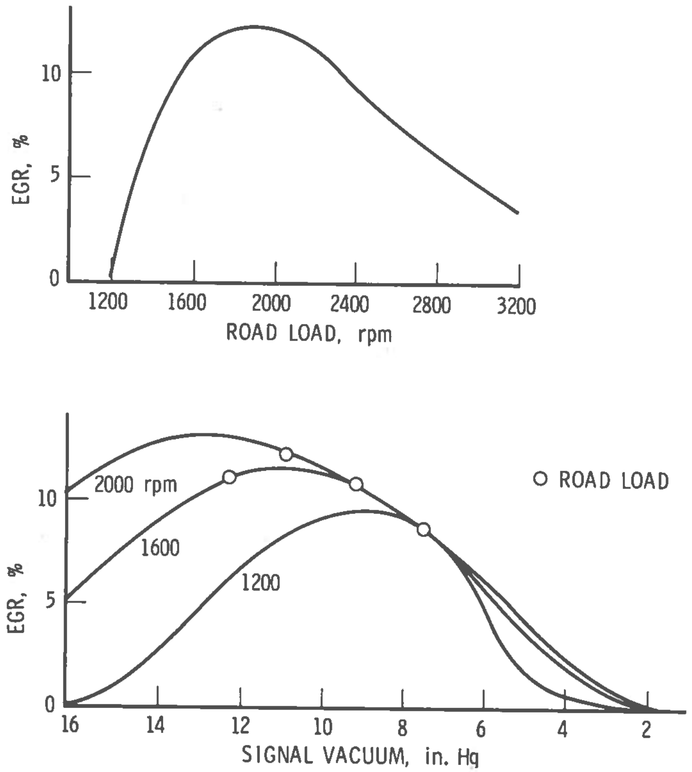


FIGURE 4-19. EGR SYSTEM PERFORMANCE: 1974 CHRYSLER 225-CID ENGINE

4.2.2.7 Exhaust Port Air Injection System

Exhaust port air injection (AIR) was introduced by Chrysler in the 1972 model year 225-CID vehicles certified for California. As indicated in Table 4-7, the system was not used in 1974 but reappeared in the 1975 and 1976 California vehicles.

The Chrysler AIR system provides a controlled amount of air, which is injected into the exhaust ports of the engine to enhance the oxidation of the HC and CO species contained in the exhaust gases leaving the cylinders.

The system consists of a belt-driven air supply pump, a diverter valve, a check valve, an air distribution manifold, and a set of injector nozzles. The diverter valve is designed to prevent backfire in the exhaust system during deceleration. Sudden throttle closure at the beginning of deceleration temporarily creates an over-rich fuel/air mixture which becomes combustible upon mixing with secondary air. The sudden rise in intake manifold vacuum during deceleration creates a vacuum under the diaphragm of the valve and pulls the valve downward against the return spring tension. This causes the air from the air pump to be momentarily diverted to the atmosphere through the diverter valve. A small hole in the diaphragm assembly equalizes the pressure on both sides of the diaphragm within 4 to 5 seconds, and the diaphragm return spring brings the diverter valve back to its normal operating position. A pressure relief valve incorporated in the diverter valve housing limits the system pressure by diverting excessive pump output to atmosphere at high engine speeds.

The check valve, located in the injection tube assembly, consists of a one-way diaphragm which prevents the flow of hot gases back into the pump in the event of a drive belt failure or air hose rupture. The air pump is designed to deliver 33 lb/hr at a speed of 1000 rpm, with a minimum discharge pressure of 1.6-in. Hg. The power consumption of the air pump is relatively small and has only a minor effect on vehicle fuel economy (Ref. 4-36).

4.2.2.8 Catalytic Converter

All 1975 and 1976 model 49-states and California Chrysler vehicles incorporating the 225-CID engine are equipped with a catalytic converter. This unit, which is used to oxidize the bulk of the unburned HC and CO species contained in the engine exhaust gases, consists of an oval stainless steel container with two monolithic cores coated with an active platinum/palladium mixture. To prevent breaking, the substrates are surrounded by stainless steel mesh. The total precious metal loading of the catalyst is 0.08 troy oz.

Since the catalyst operates at temperatures up to about 1600°F, a heat shield is used to protect the underbody of the vehicle from exposure to excessive temperatures. In addition, California vehicles are equipped with floor insulation and a guard device attached to the bottom side of the converter to prevent combustible objects from coming into direct contact with the hot converter shell.

To prevent overheating of the catalyst caused by spark plug fouling and closed-throttle deceleration, a catalyst protection system (CPS) is employed in all 1975 model year vehicles. The main components of the CPS are an electronic speed switch and a throttle positioner solenoid. The speed switch acts as a counter which picks up the pulses from the distributor and determines whether the engine speed is above or below 2000 rpm. Above 2000 rpm, the speed switch sends a signal to the throttle positioner solenoid which becomes energized and holds the throttle plate open at the fast idle position. This permits a sufficient amount of air flow through the carburetor to properly balance the air/fuel ratio and to assure more complete combustion. Conversely, below 2000 rpm, the switch deenergizes the solenoid, and the throttle is permitted to return to the curb idle position.

4.2.2.9 Crankcase Ventilation and Evaporative Emission Control Systems

All 1968-1976 model 225-CID engines, as well as the 1967 configuration certified for California, are equipped with a closed crankcase ventilation system (CCV) of the type described in Section 3. All other post-1961 Chrysler engines incorporate an open CCV system which consists of a PCV valve installed in the valve cover and a hose connecting this valve to the intake manifold.

The Chrysler evaporative control system was introduced in California in 1970 and has been in use nationwide since 1971. The system is functionally identical to the system described in Section 3.

4.2.2.10 Fuel Economy and Emissions

The city and highway fuel economy and emission certification data are listed in Tables 4-8 and 4-9 for automatic and manual transmissions, respectively (Refs. 4-16 through 4-19). It is generally recognized that vehicle weight, engine size, rear axle ratio, transmission type, and emission levels are principal factors impacting vehicle fuel economy. While the fuel economy is also affected by a number of other parameters, including tire size and type, gear ratios, vehicle drag, and accessories, these factors have remained nearly unchanged for most of the vehicles and model years considered, except that fewer pre-1972 vehicles have been equipped with A/C. Therefore, these parameters are excluded from further consideration in the following discussion.

In the evaluation of the effects of varying the calibration of the engine on vehicle economy, the city and highway fuel economy data of the certification vehicles (Tables 4-8 and 4-9) have been normalized to a common inertia weight of 2500 pounds and a common rear axle ratio of 2.94, using the normalization technique described in Section 3. The normalized data for the vehicles with automatic transmission, averaged for each model year and calibration level (49-states and California), are presented in Figure 4-20. Also shown in this figure are the average normalized city fuel economy values of the 1973 certification vehicles and of a number of 1970 model year in-use vehicles tested as part of the EPA Emission Factor Program. (Refs. 4-21 and 4-37 through 4-40). The city fuel economy of the 1973 and 1974 model vehicles has been increased by 5 percent to account for the fact that these data are based on the 1972 FTP, whereas all other vehicles have been tested in accordance with the 1975 FTP. This factor is derived from the Emission Factor Program data and is supported by recent EPA analyses of 1974 in-use vehicle data (Ref. 4-41). Since no rear axle ratio information is available for the 1970 surveillance vehicles, the fuel economy data of these vehicles have been normalized only for inertia weight. While this introduces a small error in the average fuel economy for 1970, it has little or no effect on the observed trends. The dashed portion of the figure covers the time period for which no data are available.

The corresponding average emission data are presented in Figure 4-21. Again, adjustments have been made in the 1973 and 1974 data, using the EPA-derived conversion factors of 0.88 for HC, 0.72 for CO, and 1.03 for NO_x (Ref. 4-42).

The decline in the city fuel economy of the 49-states vehicles between 1970 and 1973 is primarily attributed to the control of NO_x, implemented nationwide since 1973. While no California fuel economy data are available for 1972, these vehicles would be expected to have lower fuel economy than the corresponding 49-states because of the lower spark advance of

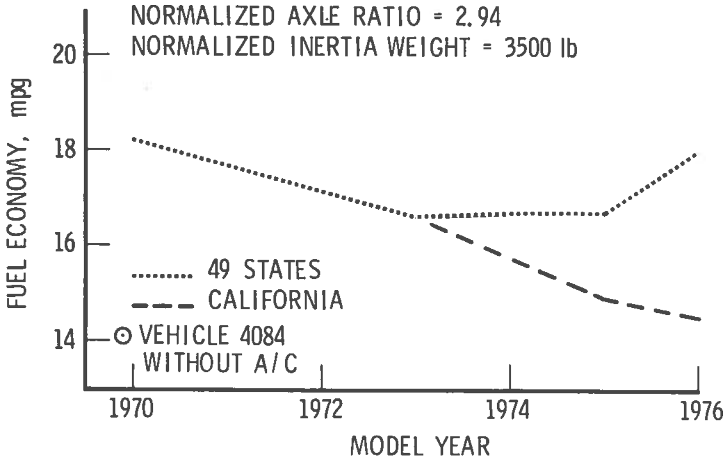


FIGURE 4-20. NORMALIZED AVERAGE CITY FUEL ECONOMY: CHRYSLER 225-CID ENGINE WITH AUTOMATIC TRANSMISSION; 1975 FTP

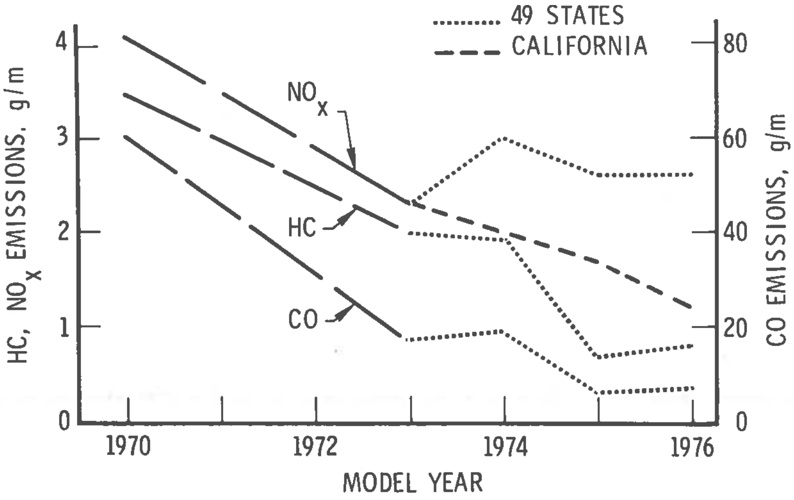


FIGURE 4-21. AVERAGE EXHAUST EMISSIONS: CHRYSLER 225-CID ENGINE WITH AUTOMATIC TRANSMISSION; 1975 FTP

the California vehicles in the low-speed regime (Table 4-8). Although the HC and NO_x emission standards were drastically reduced in 1975 relative to 1974, the fuel economy of the 49-states vehicles did not change. This is attributed to the compensating effects resulting from the use of leaner air/fuel mixtures in the part-load regime (Table 4-8) and the slight reduction in spark advance in 1975, accompanied by constant EGR flow rates for both model years. Compliance with the 1975 HC and CO emission standards has been achieved by adding a catalyst. In addition, the air/fuel ratio has been lowered at idle and in the low-load regime to maintain sufficiently high catalyst temperatures for efficient catalyst operation.

Because of substantially higher spark advance and the lack of air conditioning and OSAC, the 1976 certification vehicle No. 4084 shows better fuel economy than the other 1976 and 1975 vehicles. However, part of the large fuel economy difference might be attributed to a number of other factors, including the small data sample, the potential inaccuracies in the sensitivity coefficients used in normalizing the data, and the fact that the certification data are rounded to the nearest mile per gallon. The fuel economy difference of the other three 1976 certification vehicles, relative to 1975, is attributed primarily to these factors, because the air/fuel ratio, spark timing, and EGR valve calibrations have remained unchanged, although the use of EGR had been delayed in 1976 until the coolant temperature reached 120°F, compared to 75°F in 1975.

The lower fuel economy of the 1975 and 1976 California vehicles relative to the 1975 model 49-states configurations results from the application of higher EGR flow rates in the latter vehicles to meet the more stringent California NO_x standard. Considering the previously discussed uncertainties in the data points shown in Figure 4-20, the difference in the 1975 and 1976 California fuel economy data is insignificant. While the EGR valve calibration data listed in Table 4-8 indicate lower EGR flows for the California vehicles in 1976, the average NO_x emission is lower in 1976 than in 1975. This improvement is attributed to a slight variation in the location of the EGR vacuum port in 1976 which was implemented to increase the amount of EGR at the higher load points of the Federal driving cycle, where most of the NO_x is formed.

The normalized average city fuel economy and the average emissions of the California vehicles with manual transmission are presented in Figures 4-22 and 4-23, respectively. Again, substantially lower fuel economy is shown for the 1974 vehicles, relative to 1973, which is attributed to the higher EGR flow rates required in 1974 to meet the more stringent NO_x emission standard. Unlike the loss in fuel economy observed in the 1975 and 1976 California vehicles with automatic transmission, the manual transmission equipped vehicles show sizeable fuel economy improvements in 1975 and 1976, caused by the higher spark advance settings used in these vehicles, particularly at low engine speeds. Since NO_x increases with increasing spark advance Chrysler applied higher EGR flow rates in 1975 and improved the EGR system in 1976, as discussed previously.

The available fuel economy data for the 49-states vehicle calibration with manual transmission are limited to model year 1976, as shown in Table 4-9. The two 49-states vehicles with A/C have the same vacuum spark advance as the 1976 California vehicles but have slightly higher centrifugal advance. Since the NO_x standard is higher for the 49-states vehicles, less EGR is needed resulting in the observed fuel economy improvement. As shown in Figure 4-22, the fuel economy of the 1976 model 49-states vehicle without A/C is substantially higher than for the vehicle with A/C. Considering the higher spark advance and the lower power output requirement of the engine without A/C, much of the observed improvement is justified although the previously noted inaccuracies in the test data and in the normalizing method might account for some of the differences. To counteract the higher NO_x formation rates resulting from the use of increased spark advance, Chrysler uses more EGR in the two vehicles without A/C. Of course, if the inertia weight of the vehicle without A/C were raised to the level of the other two vehicles, the EGR flow would have to be further increased, resulting in some loss in fuel economy.

4.2.3 Chrysler 318-CID Engine

4.2.3.1 Engine Design Features

Specification data for the Chrysler 318-CID engine are listed in Table 4-10, covering model years 1967, 1972, and 1974-1976. Like the 225-CID engine discussed in Section 4.2.2, the basic design of the 318-CID

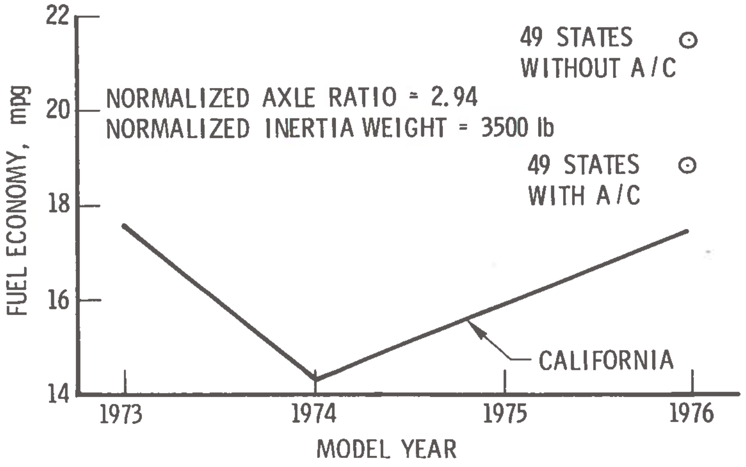


FIGURE 4-22. NORMALIZED AVERAGE CITY FUEL ECONOMY: CHRYSLER 225-CID ENGINE WITH MANUAL TRANSMISSION' 1975 FTP

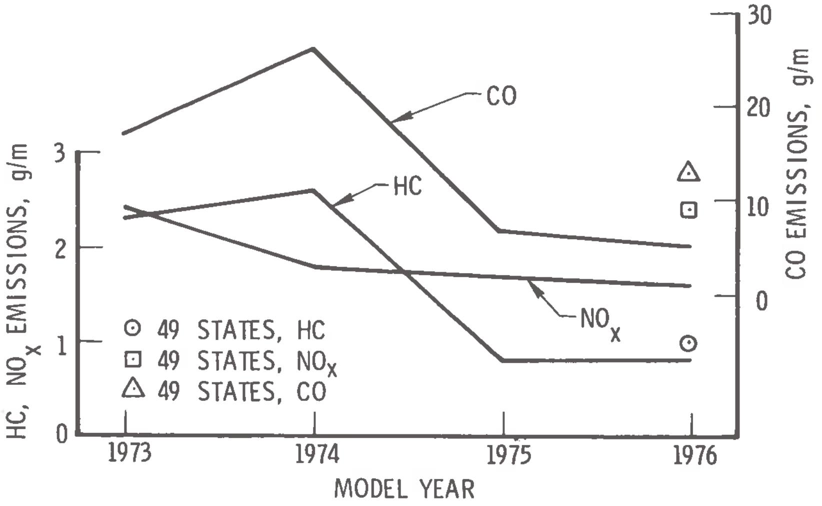


FIGURE 4-23 NORMALIZED AVERAGE CITY FUEL ECONOMY: CHRYSLER 225-CID ENGINE WITH MANUAL TRANSMISSION ; 1975 FTP; CALIFORNIA CALIBRATION

TABLE 4-10. ENGINE SPECIFICATIONS: CHRYSLER 318-CID ENGINE

Engine Parameter	Model Year									
	1976		1975		1974		1972		1967	
	49 States	California	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	8		8		8		8		8	
Bore, in.	3.91		3.91		3.91		3.91		3.91	
Stroke, in.	3.31		3.31		3.31		3.31		3.31	
Displacement, cu in.	318		318		318		318		318	
Surface/Volume, 1/in.	6.9		6.9		6.9		6.9		-	
Compression Ratio	8.5		8.5		8.5		8.5		9.2	
Cylinder Head Type	OHV		OHV		OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	-	140 at 3600	145 at 4000	140 at 4000	150 at 3600		155 at 4000		230[a] at 4400	
Torque, ft-lb, at Engine Speed, rpm	-	250 at 2000	250 at 2400	245 at 2000	265 at 2000		260 at 1600		340[a] at 2400	
Exhaust System Type	Single		Single		Single		Single		Single	
Combustion Chamber Configuration	Wedge		Wedge		Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.78		1.78		1.78		1.78		1.78	
Intake Valve Lift, in.	0.374		0.374		0.374		0.374		0.390	
Exhaust Valve Diameter, in.	1.50		1.50		1.50		1.50		1.563	
Exhaust Valve Lift, in.	0.400		0.400		0.400		0.400		-	
Intake Valve Opens, deg BTC	10		10		10		10		14	
Intake Valve Closes, deg ABC	50		50		50		50		50	
Intake Valve Duration, deg	240		240		240		240		244	
Exhaust Valve Opens, deg BBC	52		52		52		52		56	
Exhaust Valve Closes, deg ATC	16		16		16		16		8	
Exhaust Valve Duration, deg	248		248		248		248		244	
Valve Overlap, deg	26		26		26		26		22	
Distributor Type	Breakerless		Breakerless		Breakerless		Breaker point		Breaker point	
Basic Ignition Advance, deg BTC[b]	-2 or 2	0	-2[c] +2[d]	0	0		0		10 (A) 5 (M)	-5
Idle Speed, rpm[b]	900 or 750	750	900[c] 750[d]	750	750		750	750 (A) 700 (M)	500	600 (A) 650 (M)
Fast Idle Speed, rpm[b]	1200 (A) 1500 (M)	1500	1500		1500 (A) 1700 (M)	1500 (A) 1700 (M)	1700 (A) 1900 (M)	1800 (A) 2000 (M)	700	1400
Fuel System Type	2-V downdraft Carter BBD		2-V downdraft Carter BBD		2-V downdraft Carter BBD		2-V downdraft Carter BBD		2-V downdraft Stromberg WW	
Fuel Metering Method	2 orifices with metering rod		2 orifices with metering rod		2 orifices with metering rod		2 orifices with metering rod		-	
Enrichment Method	Tapered metering rod		Tapered metering rod		Tapered metering rod		2-step metering rod		-	
Choke Type	Automatic electric assist		Automatic electric assist		Automatic electric assist		Automatic		Automatic	
Carburetor Venturi Diameter, in.	1.187		1.187		1.187		1.187		1.25	
Carburetor Maximum Air Flow, cfm, at Vacuum, in. Hg	266 cfm at 2 in. Hg		266 cfm at 2 in. Hg		266 cfm at 2 in. Hg		250 cfm at 2 in. Hg		-	
Emission Control Systems	CAT[e] EGR EM EVAP PCV	AIR CAT EGR EM EVAP PCV	CAT[e] EGR EM EVAP PCV	AIR CAT EGR EM EVAP PCV	EGR EM EVAP PCV	EGR EM EVAP PCV	EM EVAP PCV	EGR EM EVAP PCV	PCV	CAP PCV
Emission Control Devices	CCEGR CCIE EGR timer Heated air OSAC[f]	CCEGR CCIE EGR timer Heated air OSAC TIDC[g]	CCEGR CCIE EGR timer Heated air OSAC TIDC[h]	CAT protection[i] CCEGR CCIE EGR timer Heated air OSAC TIDC[j]	CCEGR Heated air OSAC TIDC[f]	CCEGR EGR timer Heated air OSAC				

[a] Gross rating

[b] A = automatic transmission; M = manual transmission

[c] No catalyst

[d] With catalyst

[e] Or AIR

[f] Only in vehicles with A/C

[g] Vehicle 4176 (See Table 4-11)

[h] Vehicles 2084 and 2061 (See Table 4-11)

[i] Vehicle 2189 only

[j] Vehicle 2199 only

engine has remained essentially unchanged during the past 10-year period. However, many component modifications and additions, as well as calibration changes, have been implemented over the years to comply with the increasingly stringent emission regulations. These modifications are described in the following sections, followed by a discussion of the effects of the various modifications on vehicle fuel economy.

The 1966 and 1967 model 318-CID engines certified for use in California are equipped with the Chrysler CAP. This system, which is similar to that previously described for the 225-CID engine, is used for HC and CO emission control purposes.

4.2.3.2 Engine Modifications

In the main, the engine modifications incorporated by Chrysler in its 318-CID engine during the past 10-year period are similar to those previously noted for the 225-CID engine. These include the use of a modified camshaft with extended overlap and a redesigned combustion chamber with increased quench height. As shown in Table 4-10, the opening of the intake and exhaust valves of the 1972-1976 engines is advanced relative to 1967, resulting in higher valve overlap. This increases the amount of exhaust gas retained in the cylinder and reduces the NO_x formation during combustion. The increased quench height has been shown to be an effective technique for the control of HC emissions. In 1970, the compression ratio of the engine was reduced to 8.8 from the 9.2 used in 1967, by means of piston and head design modifications, followed by additional reductions to 8.6 in 1972 and to 8.5 in 1974. While the lower compression ratio was introduced to permit satisfactory operation of the engine on 91 octane gasoline, it has resulted in some loss in thermal efficiency, accompanied by slightly lower HC and NO_x emissions. (Refs. 4-23 through 4-32).

4.2.3.3 Intake System

Over the years, Chrysler has incorporated a number of intake manifold modifications to accelerate the fuel vaporization process during engine warmup, and to improve the homogeneity of the air/fuel mixture supplied to the individual engine cylinders. This permits the use of leaner mixtures, resulting in lower HC and CO emissions and better fuel economy. All

1971 and later model 318-CID engines are equipped with a heated intake air system of the type described in Section 4.2.2.3, which is designed to maintain a nearly constant air temperature of about 100°F in the carburetor. The floor of the intake manifold between the intake and the exhaust gases has been thinned out to accelerate the transfer of heat from the exhaust gases into the incoming charge. A thermostatic heat control valve has been employed for many years to enhance fuel vaporization and air/fuel mixing.

4.2.3.4 Carburetor

4.2.3.4.1 Design Features

As shown in Table 4-10, the Chrysler 318-CID engine has been equipped with dual-venturi, downdraft-type Carter BBD carburetors since 1972, replacing the dual-venturi Stromberg WW3 carburetor used in previous model years. Like the Holley carburetors used on the 225-CID engine, the basic design of the Carter unit has not been changed since 1972, although a number of important modifications have been incorporated during the past several years, including smaller manufacturing tolerances, different main metering jets, and improved idle and choke systems. These modifications are designed to provide better fuel metering and mixture distribution.

In principle, the idle system, the main fuel system, and the accelerator pump system are identical to those used in the 225-CID engine discussed in Section 4.2.2.3, except for the use of two main metering rods in the Carter carburetor.

4.2.3.4.2 Cold Start Control

The Carter and Stromberg carburetors identified in Table 4-10 are equipped with an automatic choke and a vacuum kick diaphragm. As in the Holley carburetor, an electric assist choke feature has been added, in 1973, to shorten the warmup time of the bimetallic choke spring. The electric assist unit incorporated in the 318-CID engine is of the dual-stage type. It includes a switch which is designed to provide partial power to the choke heater for engine temperatures below 58°F and full power above that temperature. At approximately 130°F, the power is turned off completely. In 1975, a time delay system was introduced, comprised of an electronic timer which energizes a solenoid valve for a period of 35 seconds after engine start. During that time period, the valve interrupts the flow of EGR and applies manifold vacuum to activate the idle enrichment system through a block coolant valve which prevents enrichment for block temperatures above 150°F.

As an added HC and CO control measure, the Carter carburetors used in 1975 and 1976 incorporate a dashpot which reduces the rate of throttle closure when the accelerator pedal is suddenly released.

The curb idle speed of the engine was increased from 600 rpm in 1967 to 750 rpm in most 1972 through 1976 model 318 CID engines. The higher idle speed, in conjunction with specific spark timing and carburetor settings, serves to reduce the HC emissions at the expense of a slight loss in fuel economy. To prevent "after run" a solenoid throttle stop is employed in all 1972 through 1976 engines. This device closes the throttle completely when the ignition circuit is turned off.

As indicated in Table 4-10, a fast idle speed of the order of 1500 rpm has been used in all 1972 through 1976 model engines to better overcome cold engine friction and to prevent engine stalling after a cold start. This technique, which reduces the HC and CO emissions over the cold start phase of the Federal Driving Cycle, results in a small loss in fuel economy.

4.2.3.4.3 Carburetor Calibration

Typical Carter carburetor curves, exemplified by the 1975 model year configuration, are shown in Figure 4-24 as a function of the air flow rate through the carburetor. Except for very low flows, lean air/fuel mixtures are provided by the carburetor in the part-load regime, particularly for air flow rates above 200 lb/hr. At WOT, the air/fuel ratio remains generally below stoichiometric. The air/fuel ratio calibration for California vehicles is richer than for 49-states vehicles, reflecting the more stringent HC and CO emission standards for California. As in the 225-CID engine, the air/fuel ratio tolerance band is about ±3 percent and has remained at that level for the past several years. However, the carburetor manufacturing tolerances were reduced during that time, and this has resulted in a reduction of the air/fuel ratio excursions.

The mean air/fuel ratios of the 1974-1976 California and 49-states certification vehicles at selected carburetor air flow settings are

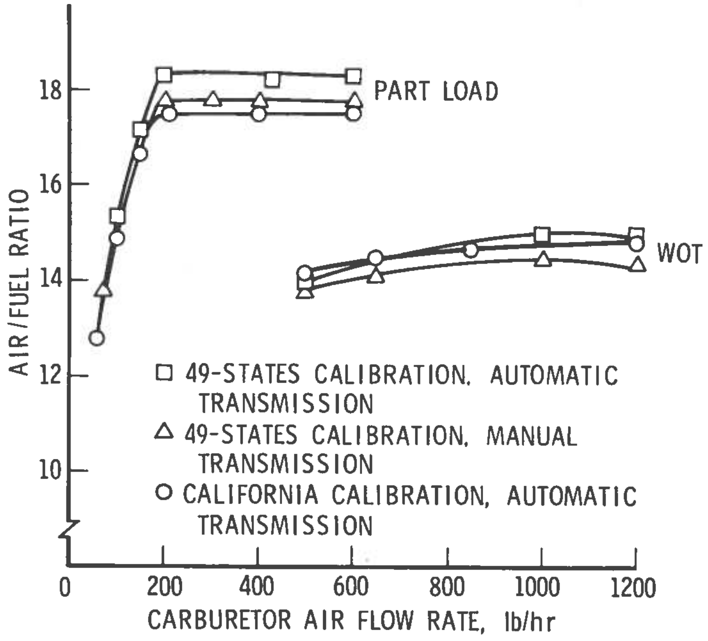


FIGURE 4-24. CARBURETOR CALIBRATION: 1975 CHRYSLER 318-CID ENGINE WITH AUTOMATIC AND MANUAL TRANSMISSION; 1975 FTP

presented in Tables 4-11 and 4-12 for automatic and manual transmissions, respectively. Also listed in Table 4-11 are the available air/fuel ratio data for the 1972 model 49-states calibration.

In the main, the air/fuel ratio used in the catalyst-equipped 1975 and 1976 model 49-states vehicles at idle is only slightly different from the 1970-1974 settings, varying between 13.3 in 1972 and 1975 to 13.8 in 1976. Similar trends are observed for the low-load condition (100-lb/hr air flow) and WOT. In the part-load regime, the air/fuel ratio remains nearly constant between 1970 and 1973, followed by a moderate increase in 1975, which has been retained in 1976. The 1975 model 49-states vehicles without catalyst exhibit somewhat different trends, showing a lower air/fuel ratio and an increase in the air/fuel ratio at part loads. The richer idle mixture is required to maintain sufficiently high temperatures in the thermal reactor for HC and CO control. In general, the air/fuel ratios of the 1975 and 1976

TABLE 4-11. CERTIFICATION CALIBRATION DATA: CHRYSLER 318-CID ENGINE WITH AUTOMATIC TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard																						
	1976 49 States						1976 California				1975 49 States					1975 California		1974 49 States	1974 Calif	1972 49 States	1972 Calif	1970	1967
Vehicle Model	Da[a]	D[b]	D[b]	Da[a]	P[c]	D[b]	D[b]	F[e]	C[f]	C[f]	D[b]	P[c]	D[b]	D[b]	P[c]	Da[a]	D[b]	P[c]	DP[g]	DP[g]	DP[g]	FC[h]	FC[h]
Vehicle Identification No.	4069	4058	4092	4097	4094	4057	4178	4177	4159	4176	2081	2083	2084	2096	2097	2189	2199	-	-	-	-	-	-
Vehicle Inertia Weight, lb	3500	4000	4500	3500	4000	4500	3500	4000	4000	4500	4500	4000	4500	4000	4000	4000	4500	4000	-	-	-	-	-
Rear Axle Ratio	2.76	2.45	2.45	2.45	2.45	2.71	3.21	2.45	2.71	2.71	3.21	3.21	2.45	3.21	2.45	2.45	3.21	2.71	-	-	-	-	-
Catalyst	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Air Conditioning A/C	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-	-	-	-
Carburetor California, A/F																							
Idle: 60-lb/min air flow	13.8	13.8	13.8	-	-	-	12.2	12.2	12.3	12.2	12.2	12.2	12.2	13.3	13.3	12.9	12.8	13.6	-	13.3	-	13.5	-
Off Idle: 100-lb/min air flow	15.3	15.3	15.3	14.1	14.1	14.1	14.0	14.0	14.3	14.0	15.3	15.3	15.3	15.1	15.1	14.9	14.8	14.4	15.1	14.8	-	14.8	-
Part Throttle: 300-600 lb/min air flow	17.2	17.2	17.2	17.3	17.3	17.3	17.5	17.5	17.5	17.7	18.1	18.1	18.1	17.2	17.2	17.8	17.2	16.4	16.8	16.1	-	16.5	-
WOT at Max.: 1200-lb/min air flow	14.8	14.8	14.8	14.5	14.5	14.5	14.5	14.4	14.7	14.8	14.9	14.9	14.9	14.5	14.5	14.6	14.5	13.9	14.1	-	-	13.9	-
Basic Timing, crankshaft deg BTC	2	2	2	-2	-2	-2	0	0	0	0	-2	-2	-2	2	2	0	0	0	0	0	0	0	10
Centrifugal Advance, crankshaft deg																							
1000 rpm	4	4	4	0	0	0	4	4.5	4	4	0	0	0	3	3	3.5	3	3.5	3	3.5	0	3.5	1
1200 rpm	11	11	11	0	0	0	10	11	10	10	0	0	0	10	10	9	10	10.5	10.5	11	4	10	2.5
1500 rpm	12	12	12	6	6	6	13.5	13	12.5	13	6	6	6	14	14	13.5	14.5	15	15	18.5	15	18.5	4.5
2000 rpm	14	14	14	16	16	16	16	15.5	14.5	14.5	16	16	16	16	16	16	16.5	18	18	20.5	20	20.5	7.5
3000 rpm	18	18	18	22	22	22	18	18	17	17.5	22	22	22	20	20	20	20	23.5	23	25	25	25	13
4000 rpm	22	22	22	28	28	28	21.5	22	21	21	28	28	28	24	24	24	23.5	29	29	29	29	29	19
5000 rpm	25	25	25	28.5	28.5	28.5	23	25	25	24	28.5	28.5	28.5	24	24	24.5	25	28.5	28.5	30	30	30	23
Vacuum Advance, crankshaft deg																							
6 in. Hg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 in. Hg	1	1	1	0	0	0	1	1	1	1	0	0	0	3.5	3.5	1.5	3	0	0	0	0	0	0
8 in. Hg	3.5	3.5	3.5	0	0	0	4.5	4	4.5	4	0	0	0	7	7	7.5	7	0	0	0	1	0	3
10 in. Hg	10.5	10.5	10.5	6.5	6.5	6.5	11	10.5	10.5	10	6.5	6.5	6.5	13.5	13.5	14	14	6.5	6	0	6	0	7
12 in. Hg	17	17	17	13	13	13	16.5	16	16.5	16	13	13	13	20.5	20.5	19.5	20	13	12.5	5.5	12.5	6	14.5
14 in. Hg	22	22	22	19.5	19.5	19.5	21.5	22	22	22	19	19	19	22	22	21.5	21.5	19	19	16	17	16	22
16 in. Hg	22	22	22	22	22	22	21.5	22	22	22	22	22	22	22	22	21.5	21.5	22	22	19	19	19	24
EGR Valve Calibration Flow, lb/hr:																							
5-in. Hg	46	46	46	40	40	40	92	93	90	93	31	31	31	40	40	103	98	40	87	0	Some	0	0
9-in. Hg	75	75	75	48	48	48	162	166	165	162	45.5	45.5	45.5	48	48	169	168	48	116	0	Some	0	0
Fuel Economy, mpg																							
City	16	16	13	12	11	11	11	13	12	11	10	11	11	13	13	12	11	11.6[i]	-	-	-	-	-
Highway	21	21	18	20	19	18	14	16	18	15	15	16	17	19	21	15	14	-	-	-	-	-	-
Exhaust Emissions, g/m																							
HC	1.2	1.5	1.2	1	1.4	1.1	0.7	0.9	0.5	0.5	1.4	1.2	1.3	0.6	0.9	0.3	0.4	3.1[i]	-	-	-	-	-
CO	3	6	4	6	7	9	2.3	3.4	4.2	4.5	7	8	9	7	12	5	8	18[i]	-	-	-	-	-
NO$_x$	1.7	2.2	2.6	2.3	2.4	3.0	1.3	1.1	1.5	1.7	2.4	2.4	2.8	2.2	0.7	1.1	1.4	2.8[i]	-	-	-	-	-

[a] Dart
[b] Dodge
[c] Plymouth
[d] Valiant
[e] Fury
[f] Coronet
[g] Dodge; Plymouth
[h] Fury; Coronet
[i] 1972 FTP

TABLE 4-12. CERTIFICATION CALIBRATION DATA: CHRYSLER 318-CID ENGINE WITH MANUAL TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard													
	1976 49 States			1975 49 States			1975 Calif	1974 49 States		1974 Calif	1972 49 States	1972 Calif	1970	1967
Vehicle Model	F[a]	F[a]	F[a]	V[b]	C[c]	Da[d]	P[e]	D[f]	P[e]	P[e]	DP[g]	DP[g]	FC[h]	FC[h]
Vehicle Identification No.	4062	4061	4061	2058	2061	2071	2161	-	-	-	-	-	-	-
Vehicle Inertia Weight, lb	4500	4000	3500	4000	4500	4000	4000	4500	4500	4000	-	-	-	-
Rear Axle Ratio	3.21	2.94	2.94	2.45	3.21	3.21	3.21	3.55	3.55	2.94	-	-	-	-
Catalyst	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
Air Conditioning	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Carburetor Calibration, A/F														
Idle: 60-lb/hr air flow	13.6	13.6	13.6	13.7	13.7	13.7	12.8	13.6	13.6	13.6	-	-	13.0	-
Off Idle: 100-lb/hr air flow	14.9	14.9	14.9	15.7	15.7	15.7	15.0	14.4	14.4	14.0	-	-	14.4	-
Part Throttle: 300-600 lb/hr air flow	17.8	17.8	17.8	17.8	17.8	17.8	17.5	16.4	16.4	17.0	-	-	16.7	-
WOT at Max.: 1200-lb/hr air flow	15.1	15.1	15.1	14.4	14.4	14.4	14.6	13.9	13.9	14.0	-	-	13.3	-
Basic Timing, crankshaft deg BTC	2	2	2	2	2	2	0	0	0	0	0	0	0	5
Centrifugal Advance, crankshaft deg														
1000 rpm	4	4	4	3	3	3	4	3.5	3.5	3.5	3.5	0	3.5	2.5
1200 rpm	11	11	11	10	10	10	11	10.5	10.5	10.5	11	4	10.5	5
1500 rpm	12	12	12	14	14	14	13.5	15	15	15	18.5	15	18.5	8.5
2000 rpm	14	14	14	16	16	16	16	18	18	18	20.5	20	20.5	12
3000 rpm	18	18	18	20	20	20	19	23.5	23.5	23.5	25	25	25	18
4000 rpm	22	22	22	24	24	24	23	29	29	29	29	29	29	24
5000 rpm	25	25	25	24	24	24	24.5	28.5	28.5	28.5	30	30	30	27
Vacuum Advance, crankshaft deg														
6 in. Hg	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 in. Hg	1	1	1	3.5	3.5	3.5	4	0	0	0	0	0	0	0
8 in. Hg	3.5	3.5	3.5	7	7	7	7.5	0	0	0	1	1	0	1.5
10 in. Hg	10.5	10.5	10.5	13.5	13.5	13.5	14	6.5	6.5	6.5	6	6	3.5	7.5
12 in. Hg	17	17	17	20.5	20.5	20.5	19.5	13	13	13	12.5	12.5	10.5	15
14 in. Hg	22	22	22	22	22	22	21.5	19	19	19	17	17	16	21.5
16 in. Hg	22	22	22	22	22	22	21.5	22	22	22	19	19	19	24
EGR Valve Calibration Flow, lb/hr														
5-in. Hg	40	40	40	28	28	28	100	30	30	75	0	Some	0	0
10-in. Hg	48	48	48	42	42	42	168	44	44	115	0	Some	0	0
Fuel Economy, mpg														
City	15	14	14	15	13	12	12	11.4[i]	11.8[i]	12.5[i]	-	-	-	-
Highway	21	22	23	25	19	20	16	-	-	-	-	-	-	-
Exhaust Emissions, g/m														
HC	0.8	1.0	1.1	0.5	0.5	0.3	0.3	2.6[i]	2.6[i]	2.8[i]	-	-	-	-
CO	7	12	8	8	14	2	4	30[i]	20[i]	33[i]	-	-	-	-
NO_x	2.2	1.8	1.7	2.8	2.8	2.6	1.5	2.6[i]	2.7[i]	1.8[i]	-	-	-	-

[a] Fury
[b] Valiant
[c] Coronet
[d] Dart
[e] Plymouth
[f] Dodge
[g] Dodge; Plymouth
[h] Fury; Coronet
[i] 1972 FTP

California vehicles at idle and low loads are lower than for the corresponding 49-states vehicles, whereas nearly the same part-load air/fuel ratios are used for the two calibration levels.

The 49-states vehicles with manual transmission (Table 4-12) indicate a 5 percent increase in the idle air/fuel ratio between 1970 and 1974, with no further change occurring through 1976. For all other air flow rates, the air/fuel ratios used in the vehicles with manual transmission are similar to the corresponding automatic transmission settings, except for small variations in the 1975 and 1976 model 49-states calibrations. It should be noted that manual transmission equipped vehicles with 318-CID engines are not offered in California in 1976.

Similar to the 225-CID engine treated in Section 4.2.2, the air/fuel mixture of the 318-CID engine has been leaned out between 1967 and 1970 as a means of reducing HC and CO emissions.

4.2.3.5 Ignition System

4.2.3.5.1 Design Features

Starting with model year 1972, Chrysler has introduced an electronic ignition system in some of its 318-CID engines, replacing the conventional breaker-point ignition system used in all pre-1972 models. All 1973 and later model year 318-CID engines are equipped with the electronic system, which is similar to the system described in Section 4.2.2.4 for the 225-CID engine.

4.2.3.5.2 Spark Timing Control Devices

As shown in Table 4-10, the 1975 and most of the 1976 model 318-CID engines incorporate OSAC to reduce NO_x during acceleration. This system, which is functionally identical to the system described in Section 4.2.2.5 for the 225-CID engine, delays spark advance during acceleration for about 25-27 seconds, except for the 1975 model 49-states vehicles with manual transmission and two of the 1975 certification vehicles with automatic transmission (vehicles 2096 and 2097). Some of the 1975 and 1976 vehicles use a thermostatic ignition distributor vacuum control (TIDC) unit, designed to protect the engine from overheating in stop-and-go traffic. When the coolant temperature reaches 225°F, the TIDC valve opens, applying manifold vacuum to the distributor, which raises the idle speed and provides additional cooling.

4.2.3.5.3 Spark Advance Schedules

The basic ignition timing and the centrifugal and vacuum advance settings employed in the Chrysler 318-CID engine are listed in Tables 4-11 and 4-12 for automatic and manual transmissions, showing the spark advance at various engine speeds and distributor port vacuum levels. Figure 4-25 provides a graphic illustration of the centrifugal spark advance including basic timing, of the 49-states vehicles with automatic transmission, plotted in terms of crank degrees versus model year and engine speed. At low engine speeds, the spark advance was reduced slightly between 1967 and 1968 to provide the required HC and CO control, in conjunction with the previously noted increase in the air/fuel ratio. In the higher engine speed regime, the spark advance has been increased by 1 or 2 deg, between 1967 and 1968, followed by an additional increase in 1970 in the midspeed regime. Between 1970 and 1976, the centrifugal advance increased slightly at low speeds but decreased somewhat at higher speeds. As shown in Table 4-11, the 1975 and 1976 model 49-states vehicles without catalyst have substantially lower spark advance at low engine speeds to assist in the control of HC and CO, by providing higher exhaust gas temperatures into the exhaust manifold at the expense of a loss in fuel economy.

In general, the vehicles with manual transmission exhibit similar trends, showing a slight increase in the spark advance between 1967 and 1972 in the midspeed regime, followed by a gradual decline through 1976. Again, the California vehicles use lower spark advance, except in 1974 when the same schedule was employed for both 49-states and California vehicles. This is reasonable because the HC and CO emission standards were nearly the same for the two calibrations.

The vacuum spark advance of the 49-states vehicles with automatic transmission is presented in Figure 4-26, showing a reduction in spark advance under all load conditions between 1967 and 1968, followed by a substantial increase in the 1972 and 1975 time period and a moderate decline in 1976. The large increase in vacuum advance in 1975, which is directly related

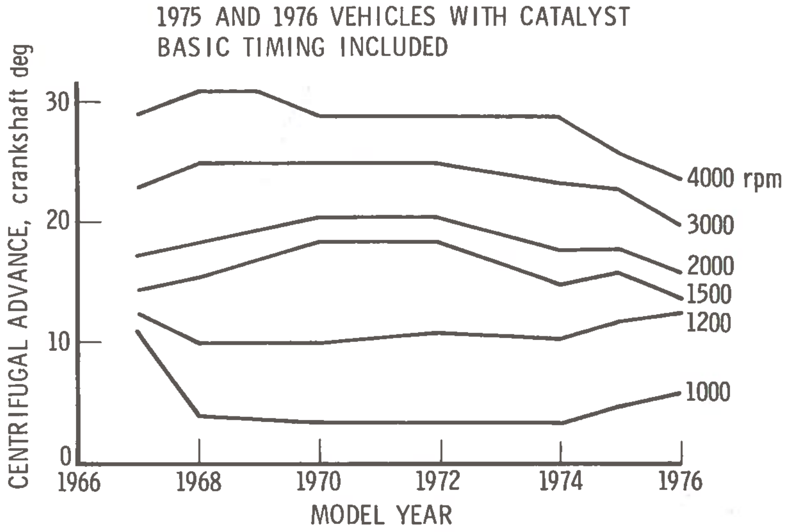


FIGURE 4-25. CENTRIFUGAL SPARK ADVANCE SCHEDULE: CHRYSLER 318-CID ENGINE WITH AUTOMATIC TRANSMISSION; 49-STATES

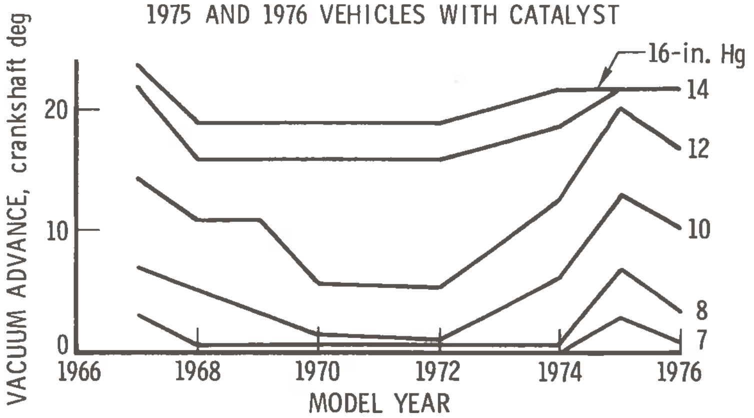


FIGURE 4-26. VACUUM SPARK ADVANCE SCHEDULE: CHRYSLER 318-CID ENGINE WITH AUTOMATIC TRANSMISSION; 49-STATES

to the use of a catalyst, more than compensates for the modest decline in centrifugal advance implemented in 1975. For control of HC and CO, considerably lower vacuum advance is used in the vehicles without catalyst than in the catalyst equipped cars.

In general, the vehicles with manual transmission exhibit similar trends. The effects of spark advance variations on fuel economy and emissions are discussed in Section 4. 2. 3. 10.

4. 2. 3. 6 Exhaust Gas Recirculation

4. 2. 3. 6. 1 Design Features

As noted in Section 4. 2. 2. 5, EGR was introduced by Chrysler in 1972 for NO_x control purposes. Initially, the EGR system consisted of an orifice in each carburetor jet, permitting a controlled amount of EGR into the engine. This simple system was replaced in 1973 by a ported vacuum control system for use in 49-states applications and by a venturi vacuum control system with vacuum amplifier for use in California. The ported vacuum system uses a slot-shaped port located in the carburetor throttle body which is exposed to an increasing percentage of manifold vacuum as the throttle blade opens. This port is connected directly to the EGR valve diaphragm chamber. Similar to the venturi vacuum controlled EGR system described in Section 4. 2. 2. 6, the flow rate through the EGR valve is controlled by throttle position, manifold vacuum, and exhaust gas backpressure. In order to restore the full power output capability of the engine at WOT, EGR is eliminated by setting the valve opening point above the manifold vacuum corresponding to WOT.

The ported vacuum EGR system is used also in all 1974 model 49-states vehicles and in most 1975 and 1976 model 49-states vehicles with a catalyst, whereas the venturi vacuum system is used in all 1974-1976 California vehicles.

To improve the cold start driveability characteristics, all 1975 and 1976 model engines and the 1974 California engines incorporate an EGR timer and solenoid delay unit and a coolant temperature control switch which cuts off EGR for coolant temperatures below about 70°F. These devices are functionally identical to those described in Section 4. 2. 2. 5 for the 225-CID engine.

4.2.3.6.2 EGR Valve Calibration

The EGR valve calibration data for the 1974-1976 certification vehicles are listed in Tables 4-11 and 4-12 for automatic and manual transmissions, respectively. Again, the EGR flow rates of the California vehicles are substantially higher than for the 49-states vehicles. While the calibration data are not sufficient to characterize the performance of the EGR system at the various operating conditions of the engine, they are useful in establishing trends.

Steady-state EGR flow rates for the 1974 California system are presented in Figure 4-27 (Ref. 4-31), showing percent EGR as a function of vehicle speed, engine rpm, and signal vacuum. Similar to the 225-CID engine, there is no EGR at low engine loads, followed by a rapid increase to about 10 percent EGR at 65 mph. While the EGR flow rate of the 225-CID

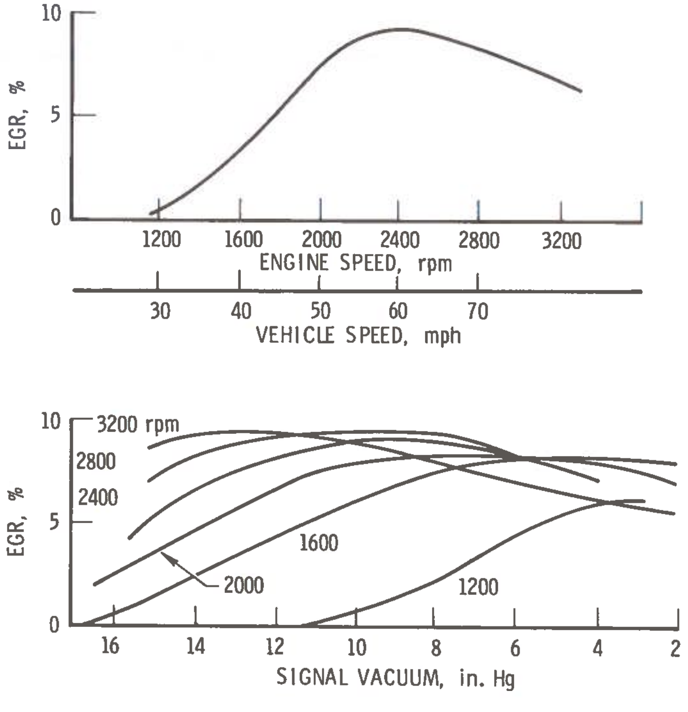


FIGURE 4-27. EGR SYSTEM PERFORMANCE: 1974 CHRYSLER 318-CID ENGINE

engine (Figure 4-19) declined rapidly at high engine loads, the decline is more gradual in the case of the 318-CID engine. The 1975 and 1976 systems show similar trends.

The transient operation of the EGR system used in the 318-CID engine equipped 1975 California vehicles is illustrated in Figure 4-28, which shows the instantaneous EGR flow rate for the second cycle of the Federal Driving Cycle (Ref. 4-31). As indicated, EGR generally increases with increasing load. The corresponding NO_x emissions are shown in Figure 4-29. which indicates good system effectiveness, except for the highly transient period between about 40 and 80 seconds.

4.2.3.7 Secondary Air Injection

As indicated in Table 4-10, AIR is used in all 1975 and 1976 California vehicles incorporating the 318-CID engine and in the 1975 49-states vehicles certified without catalyst. The AIR system, which is designed to enhance the oxidation of HC and CO species in the engine exhaust by injecting air into the engine exhaust ports, is identical to that used on the 225-CID engine described in Section 4.2.2.6.

4.2.3.8 Catalytic Converter

Except for some 1975 vehicles certified for sale outside California, all 1975 and 1976 Chrysler vehicles incorporating the 318-CID engine are equipped with a catalytic converter to meet the HC and CO emission standards. While this converter is larger than that used in conjunction with the Chrysler 6-cylinder engines, the functional details of the catalyst and catalyst protection system are identical to those described in Section 4.2.2.8.

4.2.3.9 Crankcase Ventilation and Evaporation Control Systems

These two systems are identical to the configurations described in Section 4.2.2.9 for the 225-CID engine.

4.2.3.10 Fuel Economy and Emissions

Tables 4-11 and 4-12 list the city and highway fuel economy and emissions of the 1974 through 1976 certification vehicles. (Refs. 4-15 through 4-19). Following the procedure outlined in Section 3, these data have been normalized to a common inertia weight of 4000 pounds and a common

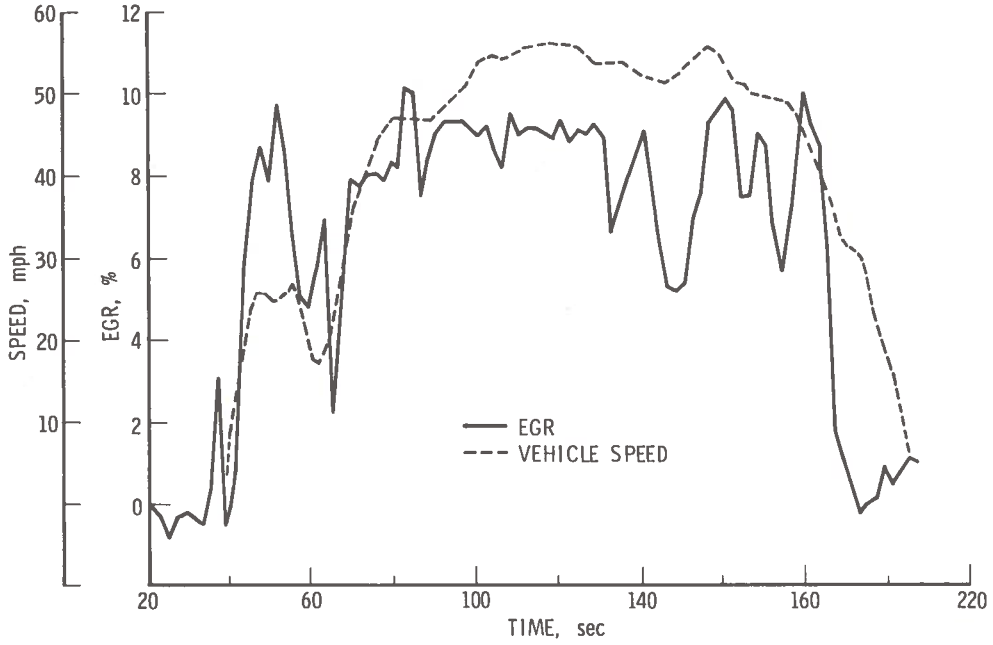


FIGURE 4-28. NO$_x$ EMISSION VERSUS TIME: 1975 CHRYSLER 318-CID ENGINE; SECOND CYCLE OF FEDERAL DRIVING CYCLE

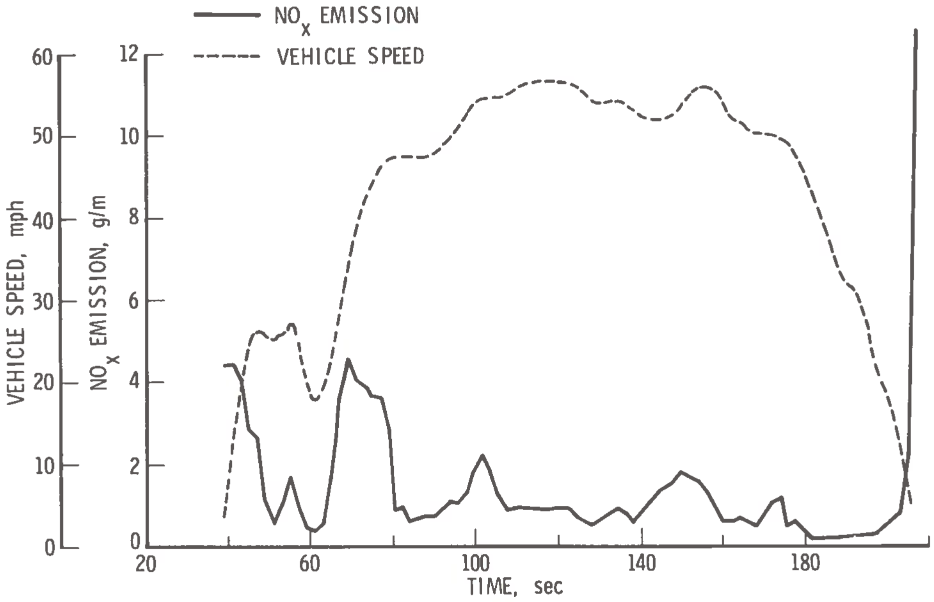


FIGURE 4-29. PERCENT EGR VERSUS TIME: 1975 CHRYSLER 318-CID ENGINE; SECOND CYCLE OF FEDERAL DRIVING CYCLE

rear axle ratio of 2.71 and are averaged at each certification level, as shown in Figures 4-30 and 4-31 for automatic and manual transmissions, respectively. Also plotted in these figures are the normalized average fuel economy of the 1973 certification vehicles (Ref. 4-21) upgraded by 5 percent to account for the different test procedures used in 1973 and 1975, and the available data for pre-1973 in-use vehicles (Refs. 4-37 through 4-40), adjusted for inertia weight variations. The corresponding average emissions are presented in Figures 4-32 and 4-33.

As shown in Figure 4-30, the fuel economy of the vehicles with automatic transmissions declined substantially between 1972 and 1974. This is attributed to the introduction of EGR in 1973 to meet the 3 g/m NO_x emission standard. The fuel economy of the 49-states vehicles without a catalyst deteriorates further in 1975 and 1976 as a direct result of the lower spark advance used for emission control. However, because of the lower NO_x formation associated with retarded spark timing, the EGR flow was reduced in the non-catalyst engines relative to the catalyst configurations, which was beneficial from a fuel economy point of view. In addition to the observed fuel economy loss, the emissions of the vehicles without catalyst are generally higher, indicating that emission control systems without a catalyst are not desirable for use in intermediate and standard size automobiles.

Considering the small changes in the air/fuel ratio and spark timing schedules of the 49-states 1975 and 1976 vehicles with catalysts, it appears that the observed fuel economy improvement might be primarily due to the use of manifold vacuum for distributor spark control in 1976 compared to the carburetor port vacuum control technique used in previous years. While this has no effect on the vacuum advance at road load speeds above about 30 mph, it accelerates the vacuum advance buildup in the low speed regime and at idle, resulting in better engine efficiency (Ref. 4-31). As expected, this modification has little impact on highway fuel economy, as shown in Table 4-11.

The lower city and highway fuel economy of the 1975 and 1976 California vehicles relative to the corresponding 49-states vehicles is attributed to the use of higher EGR flow rates and slightly retarded spark timing schedules in the California vehicles.

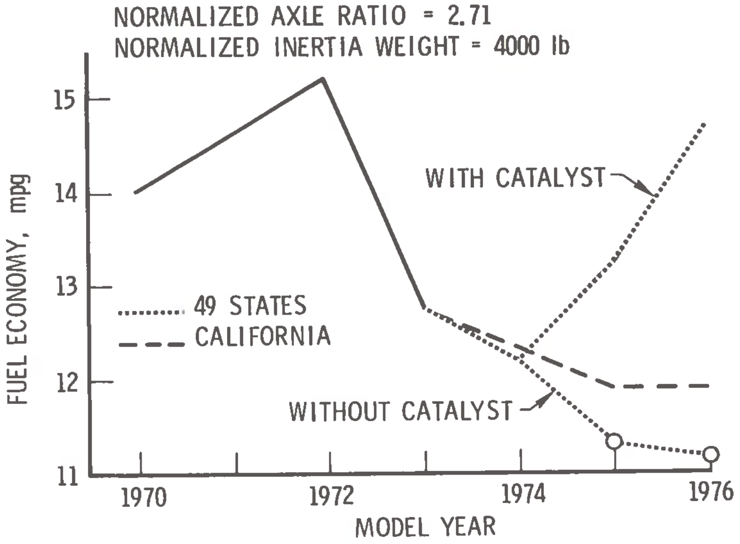


FIGURE 4-30. NORMALIZED AVERAGE CITY FUEL ECONOMY: CHRYSLER 318-CID ENGINE WITH AUTOMATIC TRANSMISSION; 1975 FTP

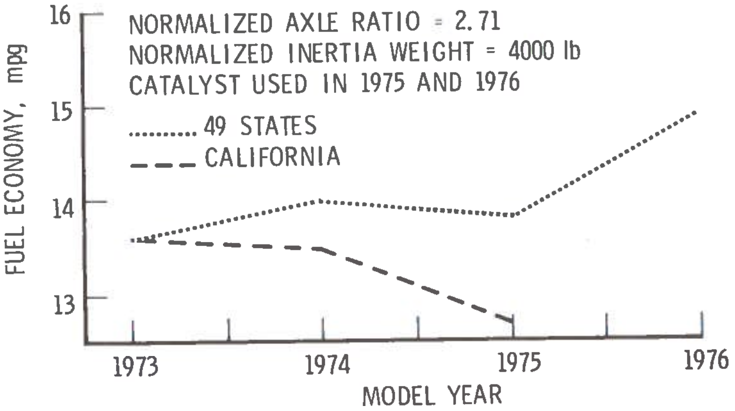


FIGURE 4-31. NORMALIZED AVERAGE CITY FUEL ECONOMY: CHRYSLER 318-CID ENGINE WITH MANUAL TRANSMISSION; 1975 FTP

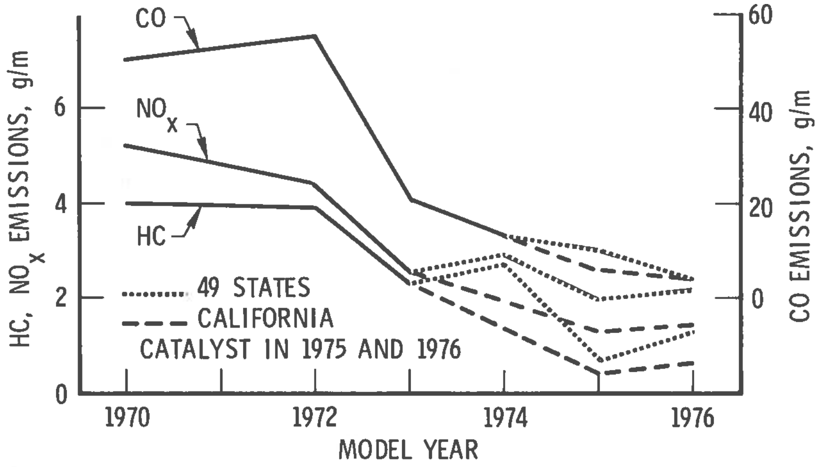


FIGURE 4-32. AVERAGE EXHAUST EMISSIONS: CHRYSLER 318-CID ENGINE WITH AUTOMATIC TRANSMISSION; 1975 FTP

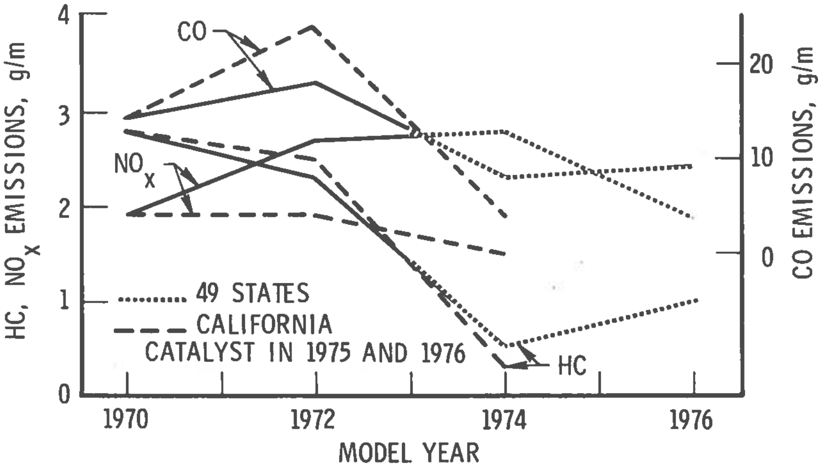


FIGURE 4-33. AVERAGE EXHAUST EMISSIONS: CHRYSLER 318-CID ENGINE WITH MANUAL TRANSMISSION; 1975 FTP

Comparison of the normalized, average city fuel economy of the 49-states and California vehicles with automatic and manual transmissions (Figures 4-30 and 4-31) generally indicates higher fuel economy for the manual transmission, except in 1976 when the performance of the two calibrations is essentially the same. Since neither spark advance nor air/fuel ratio shows significant variations at the different calibration levels, the better fuel economy of the manual transmission equipped vehicles is attributed to the higher transmission efficiency. As a result, the engine flow declines, requiring less EGR, which further improves fuel economy.

While no change in fuel economy is indicated in Figure 4-31 for the 49-states vehicles with manual transmission between 1974 and 1975, the more advanced spark used in 1975 (Table 4-12) should have resulted in some improvement in fuel economy. In this case, the apparent discrepancy might be caused by the previously noted inaccuracies in the normalization method, the small data sample and the fact that the fuel economy data published by the EPA for 1975 and 1976 vehicles are rounded to the nearest mile per gallon number. Conversely, the fuel economy improvement observed in 1976 is attributed to the use of manifold vacuum for distributor spark control.

The fuel economy loss of the 1975 California vehicles is attributed to the use of higher EGR rates in 1975, which resulted in a moderate NO_x reduction in 1976 from the 1975 level.

The highway fuel economy follows similar trends.

4.3 FORD MOTOR COMPANY

4.3.1 Engine/Vehicle Configurations

The Ford engines selected for examination in this study include the inline 4-cylinder 2.3-liter (140-CID) engine, the V-6, 2.8-liter (171-CID) engine, the inline 6-cylinder 250-CID engine, and the V-8, 351W (351-CID) engine.

The 2.3- and 2.8-liter engines were introduced in 1974 and have since been offered as standard or optional powerplants in the Pinto, Mustang II, Bobcat, and Capri II vehicles. Currently, the 250-CID engine is used primarily in the Granada, Maverick, Monarch, and Comet. In previous years, this engine was offered in a number of popular Ford and Mercury automobiles, including the Mustang, Torino, Fairlane, Falcon, Maverick, and Montego. For the past three years, the 351W engine has been available either as standard or optional equipment in the Granada, Monarch, Maverick, Montego, and Torino vehicles. Pre-1974 applications for this engine include the Cougar, Torino, and Montego.

4.3.2 Ford 2.3-Liter Engine

4.3.2.1 Engine Design Features

Table 4-13 summarizes important engine design parameters and component settings and lists the principal emission control systems incorporated since the 2.3-liter engine was introduced in 1974 (Refs. 4-43 through 4-50). While the basic engine has remained unchanged, several component modifications and additions have been implemented, in 1975 and 1976, to meet the more stringent California and Federal emission standards for these two model years. A series of other changes have been incorporated, in 1976, to improve the fuel consumption characteristics of the engine. These modifications and their effects on vehicle fuel economy and emissions are discussed in the following section.

4.3.2.2 Engine Modifications

In an effort to improve engine efficiency, Ford has increased the compression ratio of most 1976 model 2.3-liter engines from 8.4 to 9.0. The implementation of this change is possible because of the relatively small octane requirement increase (ORI) observed on this engine in 1975 with unleaded gasoline. In addition, intake and exhaust valve timing schedule modifications have been incorporated in those engines used in conjunction with an automatic transmission.

4.3.2.3 Air Intake System

All Ford 2.3-liter engines are equipped with an intake air temperature control system designed to maintain a constant air temperature of 105°F at the carburetor. The objective of this system is to improve the warmup characteristics of the engine and to permit the use of leaner air/fuel mixtures for added HC and CO emission control. The 1974 system consists of an exhaust manifold shroud and heat riser tube, a vacuum-operated duct and valve assembly, and

TABLE 4-13. ENGINE SPECIFICATIONS: FORD 140-CID (2.3-LITER) ENGINE

Engine Parameter	Model Year					
	1976		1975		1974	
	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4	
Bore, in.	3.18		3.78		3.78	
Stroke, in.	3.13		3.13		3.13	
Displacement, cu in.	140.2		140.2		140.2	
Surface/Volume, 1/in.	7.6		7.6		7.2	
Compression Ratio[a]	9.0[b]		8.4		8.4	
Cylinder Head Type	OHC		OHC		OHC	
Advertised HP at Engine Speed, rpm	85 at 4800		85.5 at 4800		88 at 5000	
Torque, ft-lb, at Engine Speed, rpm	121 at 3000		113 at 2600		116 at 2600	
Exhaust System Type	Single		Single		Single	
Combustion Chamber Configuration	Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.74		1.74		1.74	
Intake Valve Lift, in.	0.400		0.400		0.400	
Exhaust Valve Diameter, in.	1.50		1.50		1.50	
Exhaust Valve Lift, in.	0.400		0.400		0.400	
Intake Valve Opens, deg BTC[c]	30 (A) 22 (M)		22		22	
Intake Valve Closes, deg ABC[c]	58 (A) 66 (M)		66		66	
Intake Valve Duration, deg	268		268		268	
Exhaust Valve Opens, deg BBC[c]	72 (A) 64 (M)		64		64	
Exhaust Valve Closes, deg ATC[c]	16 (A) 24 (M)		24		24	
Exhaust Valve Duration, deg	268		268		268	
Valve Overlap, deg	0.41		0.41		0.41	
Distributor Type	Breakerless		Breakerless		Breaker point	
Basic Ignition Advance, deg BTC[c]	10 or 20 (A) 6 or 10 (M)		6 (A) 6 (M)	10 (A) 6 (M)	6-8 (A) 6 (M)	
Idle Speed, rpm[c]	750 (A) 850 (M)		750 (A) 850 (M)	900 (M)	750 (A) 850 (M)	
Fast Idle Speed, rpm[c]	2000 (A) 1600 (M)		1800 (A) 1600 (M)		1800 (A) 1600 (M)	
Fuel System Type	2-V downdraft Holley 5200		2-V downdraft Holley 5200		2-V downdraft Holley 5200	
Fuel Metering Method	Fixed orifice		Fixed orifice		Fixed orifice	
Enrichment Method	Vacuum-actuated power valve		Vacuum-actuated power valve		Vacuum-actuated power valve	
Choke Type	Automatic electric assist		Automatic electric assist		Automatic electric assist	
Carburetor Venturi Diameter, in.	1.02 (primary) 1.06 (secondary)		1.02 (primary) 1.06 (secondary)		1.02 (primary) 1.06 (secondary)	
Carburetor Maximum Air Flow, lb/min, at Vacuum, in. Hg	17.4 lb/min at 2 in. Hg		17 lb/min at 2 in. Hg		17 lb/min at 2 in. Hg	
Emission Control Systems	EGR AIR CAT[d] PCV EVAP	EGR AIR CAT PCV EVAP	EGR AIR PCV EVAP	EGR AIR CAT PCV EVAP	EGR AIR PCV EVAP	EGR AIR PCV EVAP

[a] No manual transmission

[b] Carryover 1975 Capri II engines have an 8.4 compression ratio.

[c] A = automatic transmission; M = manual transmission

[d] Some vehicles

a bimetallic heat sensor. As shown in Tables 4-14 and 4-15, a cold weather modulator is used in all 1975 and most 1976 model 2.3-liter engines.

The exhaust manifold of the engine and the surrounding shroud serve as the air heater. Whenever the inlet air temperature is below the design temperature, the valve is held in the "heat-on" position by the vacuum motor, and the intake air is then drawn through the heater. Conversely, when the air temperature reaches 105°F, the heat control valve located in the snorkel is activated by the bimetallic heat sensor, which interrupts the vacuum supply to the vacuum motor. As a result, the valve returns to the "heat-off" position, permitting the entry of cooler air into the air cleaner. During high vehicle acceleration, the intake manifold vacuum decreases, causing the vacuum motor to move the main valve to the "heat-off" position, thereby restoring full engine power independent of air temperature.

The cold weather modulator used in 1975 and in some 1976 engines is located in the vacuum line between the temperature sensor and the vacuum motor. It is activated during engine warmup and at low ambient temperatures to prevent the relaxation of the vacuum motor and sudden cooling of the engine intake air. The modulator is closed for temperatures below 40°F and is fully open above about 55°F.

4.3.2.4 Carburetor

4.3.2.4.1 Design Features

All 2.3-liter engines are equipped with a Motorcraft or Holley Model 5200, two-stage, two-venturi carburetor. The basic design of the two carburetors is identical and has remained unchanged since their introduction in 1974 although a number of refinements have been incorporated in 1975 and 1976. As shown in Table 4-13, the primary venturi is slightly smaller than the secondary venturi, which is operated by means of a mechanical linkeage arrangement (Refs. 4-49 and 4-50).

Both carburetor stages are equipped with independent main metering and power enrichment circuits, drawing fuel from a common fuel bowl. In addition, the primary stage incorporates a curb idle system, an accelerator pump, and a choke system. The main metering system is of the fixed orifice type, passing fuel from the bowl into the main well and

TABLE 4-14. EMISSION CONTROL SYSTEMS AND DEVICES: FORD 2.3-LITER ENGINE WITH AUTOMATIC TRANSMISSION

Engine/Vehicle System	Model Year And Certification Standard[a]														
	1976 49-States			1976 California				1975 49-States		1975 California			1974 49-States and California		
Vehicle Model	Pinto	Pinto	Capri	Capri	Capri	Pinto	Pinto	Pinto	Mustang	Mustang	Pinto	Capri	Mustang	Pinto	Pinto
Certification Calibration	6-1M-R0	6-16-R1	6-1H-R1	5-1R-R3	6-1R-R1	6-1P-R1	5-1A-R2	5-1A-R2	5-1B-R0	5-1P-R0	5-1P-R0	5-1D-R2	4-1T-R1	4-1T-R12	4-1T-R9
Vehicle Inertia Weight, lb	2750	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	2750	3000
Rear Axle Ratio	3.18	3.18	3.44	3.44	3.44	3.18	3.40	3.40	3.55	3.55	3.40	3.44	3.55	3.40	3.40
Emission Control Systems															
Air Injection	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
EGR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Oxidation Catalyst	x	x	x	x	x	x				x	x				
Crankcase Ventilation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Evaporative Control	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Emission Control Devices															
Water-Heated Choke	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Electric Assist Choke	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Hot Idle Compensator	x	x	x		x										
Fuel Deceleration Valve	x	x	x				x	x	x	x	x	x			
Air Cleaner Bimetal Sensor	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Duct and Valve	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Cold Weather Modulator	x	x	x	x	x	x	x	x	x	x	x	x			
EGR Valve[b]	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem
EGR Venturi Vacuum Amplifier				Biased			Biased	Biased	Biased	Biased	Biased	Unbiased	Unbiased	Biased	Biased
Amplifier External Vacuum Check Valve				x	x	x	x	x	x	x	x	x			
EGR Vacuum Control Valve	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
EGR Delay Valve							x	x	x			x			
Distributor Vacuum Control Valve				x	x	x	x	x	x	x	x	x	x	x	x
Spark Delay Valve				x	x	x	x	x	x	x	x	x	x	x	x
Thermactor Air Pump	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Thermactor Air Bypass and Check Valves	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Thermactor Vacuum Differential Valve										x	x				
Cold Lockout Air Cleaner TAV Switch[c]	x	x	x	x	x	x				x	x				
Floorpan Mounted Thermal Switch				x											

[a] X indicates system is used in model year shown, [b] Tap stem = Tapered stem, [c] Temperature-activated valve

TABLE 4-15. EMISSION CONTROL SYSTEMS AND DEVICES: FORD 2.3-LITER ENGINE WITH MANUAL TRANSMISSION

Engine/Vehicle System	Model Year And Certification Standard[a]											
	1976 49-States				1976 California		1975 49-States		1975 California		1974 49-States & California	
Vehicle Model	Capri	Pinto	Mustang	Mustang	Capri	Mustang	Pinto	Mustang	Pinto	Mustang	Pinto	Mustang
Certification Calibration	5-2D-R1	6-2M-R2	6-2K-R0	6-2G-R1	5-2R-R2	6-2N-R3	5-2A-R3	5-2A-R3	5-2N-R1	5-2N-R1	4-1U-R6	4-1U-R1
Vehicle Inertia Weight, lb	3000	2750	3000	3000	3000	3000	3000	3000	3000	3000	2750	3000
Rear Axle Ratio	3.44	3.00	2.79	2.79	3.44	3.40	3.55	3.55	3.40	3.55	3.40	3.55
Emission Control Systems												
Air Injection	x	x	x	x	x	x	x	x	x	x	x	x
EGR	x	x	x	x	x	x	x	x	x	x	x	x
Oxidation Catalyst		x	x	x	x	x			x	x		
Crankcase Ventilation	x	x	x	x	x	x	x	x	x	x	x	x
Evaporative Control	x	x	x	x	x	x	x	x	x	x	x	x
Emission Control Devices												
Water-Heated Choke	x	x	x	x	x	x	x	x	x	x	x	x
Electric Assist Choke	x	x	x	x	x	x	x	x	x	x	x	x
Hot Idle Compensator		x	x	x								
Fuel Deceleration Valve	x	x	x	x		x	x	x	x	x		
Air Cleaner Bimetal Sensor	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Duct and Valve	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Cold Weather Modulator	x				x	x	x	x	x	x		
EGR Valve[b]	Tap stem Unbiased	Tap stem	Tap stem	Tap stem	Tap stem Biased	Tap stem	Tap stem Biased	Tap stem Biased	Tap stem Biased	Tap stem Biased	Tap stem Unibased	Tap stem Unbiased
EGR Venturi Vacuum Amplifier												
Amplifier External Vacuum Check Valve	x				x	x	x	x	x	x		
EGR Vacuum Control Valve	x	x	x	x	x	x	x	x	x	x	x	x
EGR Delay Valve	x						x	x				
Distributor Vacuum Control Valve	x				x	x	x	x	x	x	x	x
Spark Delay Valve	x				x	x	x	x	x	x	x	x
Thermactor Air Pump	x	x	x	x	x	x	x	x	x	x	x	x
Thermactor Air Bypass and Check Valves	x	x	x	x	x	x	x	x	x	x	x	x
Thermactor Vacuum Differential Valve									x	x		
Cold Lockout Air Cleaner TAV Switch[c]		x	x	x	x	x			x	x		
Floorpan Mounted Thermal Switch					x							

[a] X indicates system is used in model year shown, [b] Tap stem = tapered stem, [c] Temperature-activated valve

through the emulsion tube into the discharge nozzle located in the carburetor venturi. A number of air bleed holes are incorporated in the emulsion tube, permitting mixing of the fuel with air drawn into the system through the main air bleed. The use of fuel/air mixture instead of fuel only enhances the fuel vaporization process and increases the response of the system to sudden variations in the throttle position.

The power enrichment system of the primary circuit is actuated by a piston/rod arrangement operated by manifold vacuum. When activated, additional fuel is admitted into the main well through the power valve and power valve restriction. The secondary power system is operated by the vacuum created in the secondary venturi, causing fuel to flow from the bowl through a restriction and into the air horn.

The primary side of the carburetor is equipped with an adjustable curb idle system, while the secondary side has a fixed idle system which is designed to provide fuel before the secondary throttle opens.

The accelerator pump used in this carburetor is of conventional design, using a diaphragm located in the main carburetor body which is activated when the pump operating lever is actuated by the throttle movement. The fuel flow provided by the movement of the diaphragm is discharged into the primary side of the carburetor.

4.3.2.4.2 Cold Start Control

As shown in Tables 4-14 and 4-15, all 2.3-liter engines are equipped with an automatic water-heated choke with electric assist heating. Water from the engine cooling system is routed through the choke housing to accelerate the warmup of the bimetallic spring controlling the position of the choke. In addition, a supplemental electric heating device is used which limits the choke period to about 1-2 minutes for warm ambient conditions when engine operation is satisfactory after a short choke period. This heater is wired from the alternator through a thermal switch which breaks the circuit for choke housing temperatures below about 60°F. Conversely, above 60°F, the circuit is closed, providing power to the ceramic heater element. The shorter choke period results in a reduction of the HC and CO emissions during the cold start phase of the engine, accompanied by a small improvement in fuel economy.

4.3.2.4.3 Other Devices

All 1975 and most 1976 model 2.3-liter engines are equipped with a number of additional devices designed to assist in the emission control of the engine. These include a fuel deceleration valve (FDV), a throttle solenoid positioner (TSP), a choke assist spring, and a fast idle cam latch. The FDV, which is attached to the intake manifold and connected to the carburetor float bowl, is designed to provide a rich fuel/air mixture into the engine intake for HC and CO control purposes whenever the manifold vacuum exceeds 20-in. Hg. In general, levels of that magnitude are only encountered during vehicle deceleration. The TSP acts as a variable throttle stop, providing an adjustable throttle plate opening for a specified idle speed, combined with enough throttle plate closing to prevent "dieseling" of the engine after the ignition key has been turned off. The choke assist spring is a simple tension spring which assists the bimetal spring in closing the choke plate, particularly with warmer choke housing temperatures. After choke pulldown is achieved, the effect of the spring is negligible, and normal bimetal spring operation is resumed.

The fast idle cam latch includes a pin and a small bimetal leaf. When the choke plate closes, the leaf latches the pin and prevents the fast idle cam from being trapped by the fast idle linkage during engine acceleration. After the leaf heats up and deflects, normal operation of the fast idle cam is resumed. The choke assist spring and idle cam latch are used also in 1976.

Some 1976 engines incorporate a hot idle compensator which is designed to alleviate hot fuel handling problems by providing engine cooling in case of excessive engine temperatures. When open, the compensator bleeds air into the intake manifold, increasing the idle speed and cooling the engine. This unit remains closed below 155°F and is fully open at 175°F.

4.3.2.4.4 Carburetor Calibration

Typical 2.3-liter carburetor calibration data, exemplified by two 1976 model 49-states and California calibrations (calibrations 6-1G-R1 and 6-1P-R1), are presented in Figure 4-34. The carburetor provides a rich mixture at idle, off idle, and WOT. Conversely, in the part-load regime the 49-states calibration varies between stoichiometric and about 10 percent lean, whereas the California calibration covers the range between slightly below and slightly above stoichiometric. In general, Ford uses lower air/fuel ratios in its California vehicles as part of the overall emission control approach selected to meet the California emission regulations.

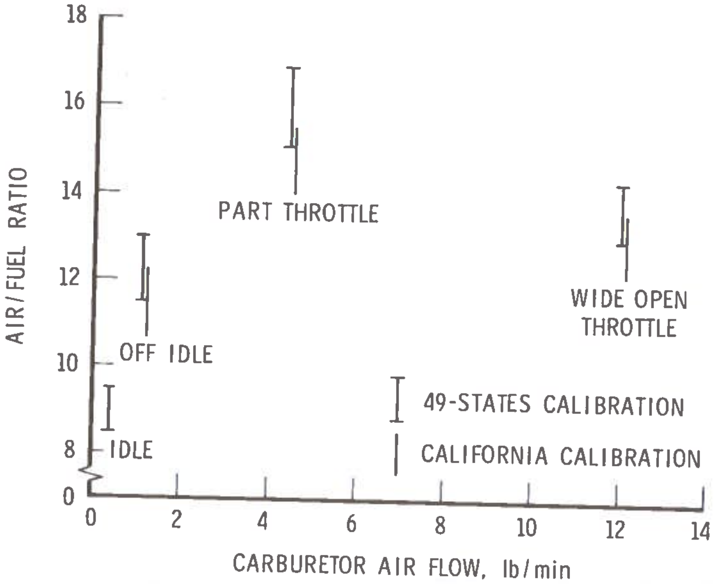


FIGURE 4-34. CARBURETOR CALIBRATION: 1976 FORD 2.3-LITER ENGINE WITH AUTOMATIC TRANSMISSION

The carburetor calibration data for the certification vehicles considered in this study are listed in Tables 4-16 and 4-17 for automatic and manual transmissions, respectively, showing the mean air/fuel ratio at idle, off idle, part-throttle, and WOT (Refs. 4-43 through 4-48). The air/fuel ratio tolerance band of the carburetor has remained nearly constant between 1974 and 1976. As shown in Table 4-16, the idle and off-idle air/fuel ratio of the 49-states vehicles shows declining trends between 1974 and 1976, particularly for the vehicles with catalyst. At part-throttle, the mixture was leaned out in 1975, followed by a moderate reduction in 1976. Conversely, the WOT setting has been held nearly constant over the years to maintain the full power output capability of the engine. There is little incentive for derating the engine because WOT operation is generally not required during the certification test. The 49-states vehicles with manual transmission as well as the California vehicles exhibit similar air/fuel ratio trends. In general, the air/fuel mixtures

TABLE 4-16. CERTIFICATION CALIBRATION DATA: FORD 2.3-LITER ENGINE WITH AUTOMATIC TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard															
	1976 49 States				1976 California			1975 49 States			1975 California		1974 49 States and California		
Vehicle Model	Ca^c	P^b	P^b	Ca^c	Ca^c	Ca^c	P^b	P^b	P^b	Mu^a	Mu^a	P^b	Mu^a	P^b	P^b
Certification Calibration	5-1D -R2	6-1M -R0	6-1G -R1	6-1H -R1	5-1R -R3	6-1R -R1	6-1P -R1	5-1A -R2	5-1A -R2	5-1B -R0	5-1P -R0	5-1P -R0	4-1T -R1	4-1T -R12	4-1T -R9
Vehicle Inertia Weight, lb	3000	2750	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	2750	3000
Rear Axle Ratio	3.44	3.18	3.18	3.44	3.44	3.44	3.18	3.40	3.40	3.55	3.55	3.40	3.55	3.40	3.40
Catalyst	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No	No	No
Carburetor Calibration, A/F															
Idle	11.6	8.8	9.0	8.7	10.5	8.9	8.9	10.6	10.6	10.6	9.3	9.3	11.8	11.9	11.6
Off Idle	12.3	12.0	12.2	12.1	11.3	11.5	11.5	13.5	13.5	13.5	12.2	12.2	13.2	11.7	13.2
Part Throttle	15.4	16.0	16.0	16.0	14.8	14.8	14.8	17.0	17.0	17.0	15.1	15.1	15.1	14.8	15.1
WOT at Max.	13.0	13.5	13.5	13.5	13.2	13.0	12.9	13.8	13.8	13.8	13.9	13.9	13.2	13.0	13.2
Basic Timing, crankshaft deg BTC	10	20	20	20	10	20	20	6	6	6	10	10	6	8	6
Centrifugal Advance, crankshaft deg															
1000 rpm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1500 rpm	3	-1	-1	-1	3	-1	-1	4	4	4	4	4	3.5	3.5	3.5
2000 rpm	8	1	1	1	8	1	1	12	12	12	7.5	7.5	10	8	10
3000 rpm	14	5	5	5	14	5	5	17	17	17	13	13	21	14	21
4000 rpm	20	9	9	9	20	9	9	23	23	23	18	18	25	20	25
5000 rpm	23	12	12	12	23	12	12	25.5	25.5	25.5	23	23	29	25	29
Vacuum Advance, crankshaft deg															
5 in. Hg	1	4	4	4	2	4	4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
6 in. Hg	5	7	7	7	5.5	7.5	7.5	4	4	4	3.5	3.5	5	4	5
8 in. Hg	12	13	13	13	12	13.5	13.5	8	8	8	8	8	10.5	8	10.5
10 in. Hg	12	17	17	17	12	17.5	17.5	8	8	8	8	8	12	8	12
12 in. Hg	12	21	21	21	12	21	21	8	8	8	8	8	12	8	12
15 in. Hg	12	24	24	24	12	23	23	8	8	8	8	8	12	8	12
20 in. Hg	12	24	24	24	12	23	23	8	8	8	8	8	12	8	12
EGR Valve Calibration															
Signal Pressure To Open, in. Hg	2.9	2.8	2.8	2.8	2.8	2.8	2.8	4.7	4.7	3.8	2.8	2.8	2.8	2.8	2.8
Flow at 12-in. Hg, cfm	6.4	11.4	11.4	11.4	14.9	14.9	14.9	7.2	7.2	8.2	14.9	14.9	14.9	14.9	14.9
Fuel Economy, mpg[d]															
City	18	22	22	19	18	20	21	17	18	18	17	18	17.8	17.5	17.4
Highway	25	33	31	26	26	28	32	25	26	24	24	26	-	-	-
Exhaust Emissions, g/m															
HC	0.7	0.7	0.7	0.6	0.3	0.9	0.4	0.8	1.0	0.7	0.2	0.3	0.8[e]	1.5[e]	1.4[e]
CO	12	9	4	5	8.5	8	3	8	13	7	3.4	5.5	19[e]	30[e]	35[e]
NO_x	2.3	2.0	2.3	2.0	1.0	1.4	1.2	2.3	2.5	2.2	1.1	1.1	1.4[e]	1.6[e]	1.7[e]

[a] Mustang
[b] Pinto
[c] Capri
[d] 1975 FTP
[e] 1972 FTP

TABLE 4-17. CERTIFICATION CALIBRATION DATA: FORD 2.3-LITER ENGINE WITH MANUAL TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard											
	1976 49 States			1976 California			1975 49 States		1975 California		1974 49 States and California	
Vehicle Model	Ca[c]	P[a]	MU[b]	MU[b]	Ca[c]	MU[b]	P[a]	MU[b]	P[a]	MU[b]	P[a]	MU[b]
Certification Calibration	5-2D -R1	6-2M -R2	5-2K -R0	6-2G -R1	5-2R -R2	6-2N -R3	5-2A -R3	5-2A -R3	5-2N -R1	5-2N -R1	4-1U -R6	4-1U -R1
Vehicle Inertia Weight, lb	3000	2750	3000	3000	3000	3000	3000	3000	3000	3000	2750	3000
Rear Axle Ratio	3.44	3.00	2.79	2.79	3.44	3.40	3.55	3.55	3.40	3.55	3.40	3.55
Catalyst	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No
Carburetor Calibration, A/F												
Idle	10.7	7.1	7.1	7.1	9.7	8.0	10.6	10.6	10.5	10.5	12.3	12.3
Off Idle	11.9	11.7	11.7	11.7	10.3	11.6	13.5	13.5	13.1	13.1	13.5	13.5
Part Throttle	16.4	16.7	15.0	15.1	14.6	14.9	16.4	16.4	14.9	14.9	15.1	15.1
WOT	13.1	13.9	13.2	13.3	13.2	13.3	13.1	13.1	13.1	13.1	13.1	13.1
Basic Timing, crankshaft deg BTC	10	6	6	6	10	6	6	6	6	6	6	6
Centrifugal Advance, crankshaft deg												
1000 rpm	-1	0	0	0	0	0	0	0	0	0	0	0
1500 rpm	3	9	9	9	3	5	4	4	3	3	5	5
2000 rpm	8	11.5	11.5	11.5	8	10	12	12	10	10	14	14
3000 rpm	14	16	16	16	13.5	16	17	17	18	18	21	21
4000 rpm	20	20.5	20.5	20.5	20	22.5	23	23	24	24	26	26
5000 rpm	23	25	25	25	23	28	25.5	25.5	25.5	25.5	29	29
Vacuum Advance, crankshaft deg												
5 in. Hg	2	7	7	7	2	9	1.5	1.5	1.5	1.5	1.5	1.5
6 in. Hg	4	11	11	11	3.5	12	4	4	3.5	3.5	5	5
8 in. Hg	8	17	17	17	8	17.5	8	8	8	8	8	8
10 in. Hg	8	21	21	21	8	21.5	8	8	8	8	8	8
12 in. Hg	8	24	24	24	8	23	8	8	8	8	8	8
15 in. Hg	8	24	24	24	8	23	8	8	8	8	8	8
20 in. Hg	8	24	24	24	8	23	8	8	8	8	8	8
EGR Valve Calibration												
Signal Pressure To Open, in. Hg	2.6	2.6	3.0	2.8	3.8	2.8	2.6	2.6	3.0	3.0	2.8	2.8
Flow at 12-in. Hg, cfm	2.9	2.9	7.2	11.4	8.6	11.4	2.9	2.9	7.2	7.2	13.3	13.3
Fuel Economy, mpg[d]												
City	18	25	22	22	19	20	19	17	16	16	-	17.3
Highway	27	38	34	32	29	30	28	29	23	24	-	-
Exhaust Emissions, g/m												
HC	0.9	1.0	1.4	1.2	0.9	0.5	0.9	0.9	0.2	0.2	2.3[e]	2.2[e]
CO	10	5	12	10	9	4	13	12	3	3	21[e]	31[e]
NO_x	2.0	2.9	1.7	1.9	1.5	1.3	2.3	2.7	0.9	1.2	1.4[e]	1.7[e]

[a] Pinto
[b] Mustang
[c] Capri
[d] 1975 FTP
[e] 1972 FTP

used in the California vehicles are slightly richer than for the 49-states vehicles, particularly in the part-throttle regime.

While the air/fuel ratios listed in Tables 4-16 and 4-17 are not always consistent with optimum fuel economy and/or emissions settings, these calibrations, combined with many other engine component adjustments, have been determined by Ford to represent acceptable compromises between full economy, emissions, and driveability.

4.3.2.5 Ignition System

4.3.2.5.1 Design Features

The Ford 1974 model 2.3-liter engine incorporates a conventional breaker-point ignition system, whereas a breakerless solid-state unit is used in all 1975 and 1976 engines. Both systems are equipped with conventional centrifugal and vacuum advance mechanisms. The principal advantage of the breakerless system is the elimination of breaker-point deterioration and attendent misfiring, resulting in better HC control over the life of the engine.

The breakerless ignition system consists of a conventional ballast resistor and ignition switch, plus a number of new components, including the ignition coil distributor and solid-state electronic switching module. The ignition coil of the breakerless system incorporates a low resistance primary winding to compensate for the added impedence of the electronic switch used in the system. The new distributor is functionally identical to a conventional distributor, except that the ignition cam, breaker-points, condensor, and breaker plate assembly have been replaced by a new variable reluctance magnetic generator consisting of a sintered armature, which turns with the distributor shaft, and a new breaker plate incorporating the magnetic starter and pickup coil. The electric switching module includes a solid-state electronic amplifier switch which receives the generator output signal from the distributor and controls the current through the primary windings of the ignition coil.

All 1974-1976 certification vehicles considered in Tables 4-14 and 4-15 employ a single diaphragm distributor, except for the two 1975 California vehicles with manual transmission, which are equipped with a dual diaphragm vacuum advance system operating from two independent vacuum sources. As in the single diaphragm distributor, the outer or primary diaphragm senses carburetor vacuum and provides spark advance in accordance with the prescribed schedule. Conversely, the inner diaphragm senses manifold vacuum and retards the spark during idle and closed throttle deceleration, thereby assisting in the control of HC emissions. When applying intake manifold vacuum to the inner diaphragm, the diaphragm moves inward toward the distributor causing movement of the advance spring and outer diaphragm in the retard direction.

4.3.2.5.2 Spark Timing Control Devices

As shown in Tables 4-14 and 4-15, most 1974-1976 model year 2.3-liter engines incorporate a distributor vacuum control valve (PVS) and a spark delay valve. The PVS is a three-port engine coolant temperature-controlled vacuum switch which is connected to the carburetor spark port, the intake manifold vacuum, and the distributor vacuum advance unit. When the coolant reaches about 210°F, the PVS switches the distributor part-throttle spark signal from carburetor port vacuum to intake manifold vacuum. This increases the spark advance and provides engine cooling.

The spark delay valve (SDV) is designed to aid in the HC emission control by delaying the vacuum advance during periods of mild vehicle acceleration. The SDV which contains a high flow resistance sintered metal disk is installed in series between the carburetor spark part and the advance side of the distributor. At high vehicle acceleration, port vacuum decreases, and the pressure difference across the restrictor disk reverses, causing a check valve to open so that transfer of the decreasing vacuum is not delayed by the restrictor plate. As a result, full engine power is available when needed. Since no change in vacuum occurs during vehicle cruise, the flow restriction in the SDV has no effect on the steady-state settings. The advance delay used in conjunction with the manual transmission is almost twice as long as for the automatic transmission, reflecting the larger HC and CO emission excursions frequently obtained with manual transmission over the Federal Driving Cycle.

4.3.2.5.3 Spark Advance Schedules

Typical centrifugal and vacuum advance schedules, exemplified by the 1976 49-states calibration for vehicles with catalyst and manual transmission, are presented in Figure 4-35. The upper curves represent the production band limits of the centrifugal advance plotted in terms of crankshaft degrees versus engine speed, whereas the lower curves show the vacuum advance band limits as a function of distributor vacuum. In general, the dispersions observed on the individual distributors are less than permitted by the band limits. Basic timing is not included in Figure 4-35.

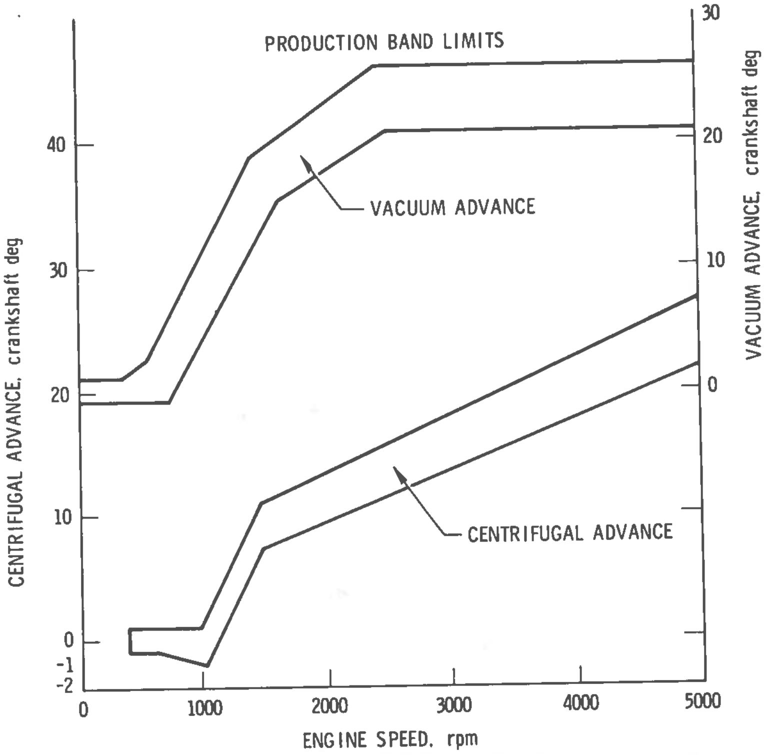


FIGURE 4-35. TYPICAL FORD SPARK ADVANCE SCHEDULE: 2.3-LITER ENGINE WITH MANUAL TRANSMISSION; 49-STATES CALIBRATION

As shown in Figure 4-35, the centrifugal spark advance commences at about 1000 rpm and increases rapidly to about 9 deg BTC at 1500 rpm, followed by a more gradual increase to 25 deg BTC at 5000 rpm. The vacuum advance starts at about 2-in. Hg of distributor vacuum, reaching a level of 24 deg BTC at 13-in. Hg. The total spark advance at each operating point of the engine is the sum of the centrifugal advance, vacuum advance, and basic timing, which was 6 deg BTC for the particular calibration discussed here.

The centrifugal and vacuum advance of the certification vehicles at selected engine speed and port vacuum settings are listed in Tables 4-16 and 4-17 for automatic and manual transmissions, respectively, (Refs. 4-43 through 4-50). Based on these data, the curves plotted in Figures 4-36 and 4-37 were generated, showing the average centrifugal and vacuum advance of the 49-states vehicles with automatic transmission. Basic timing is included in the centrifugal advance curves. As indicated in Figure 4-36, the vehicles without catalyst show only small variations in the centrifugal advance between 1974 and 1976, except for a 3-deg increase in spark advance in 1976 at 1000 rpm. Conversely, the centrifugal advance of the catalyst equipped vehicles at 1000 rpm has been substantially increased, between 1975 and 1976, with smaller increases shown for the midspeed regime. Similar trends are observed for the 49-states vehicles with manual transmission and for the California vehicles. The effect of these changes on fuel economy and emissions is discussed in Section 4. 3. 2. 10.

The vacuum spark advance schedules show little variation between 1974 and 1975, except for a 3-deg decline at high vacuum settings. Conversely, the vacuum advance has been substantially increased, in 1976, particularly at medium-to-high vacuum levels. While the vacuum advance of the California vehicles in the high-load regime (low vacuum) is comparable to the 49-states calibrations, less advance is employed in California at medium loads, reflecting the more stringent California emission regulations. The vehicles with manual transmission show similar trends.

4. 3. 2. 6 Exhaust Gas Recirculation

4. 3. 2. 6. 1 Design Features

All 2. 3-liter engines are equipped with an EGR system for NO_x control (Tables 4-14 and 4-15). The system used in 1974 and in most 1975 and 1976 vehicles consists of an EGR flow control valve, a venturi vacuum amplifier, and an EGR PVS. The vacuum-operated tapered stem-type flow

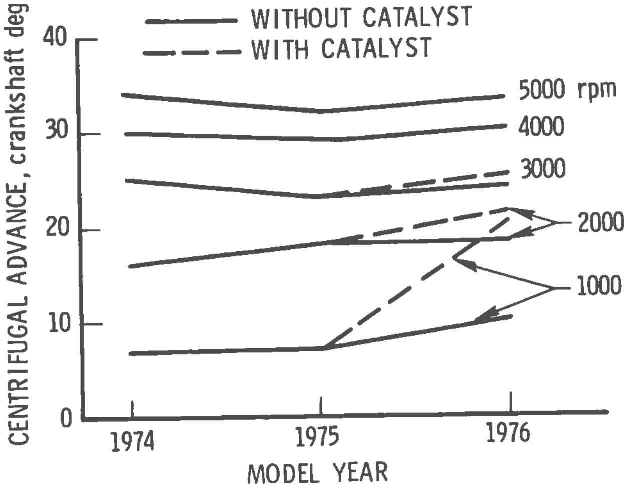


FIGURE 4-36. AVERAGE CENTRIFUGAL SPARK ADVANCE SCHEDULE: FORD 2. 3-LITER ENGINE WITH AUTOMATIC TRANSMISSION; 49-STATES CALIBRATION

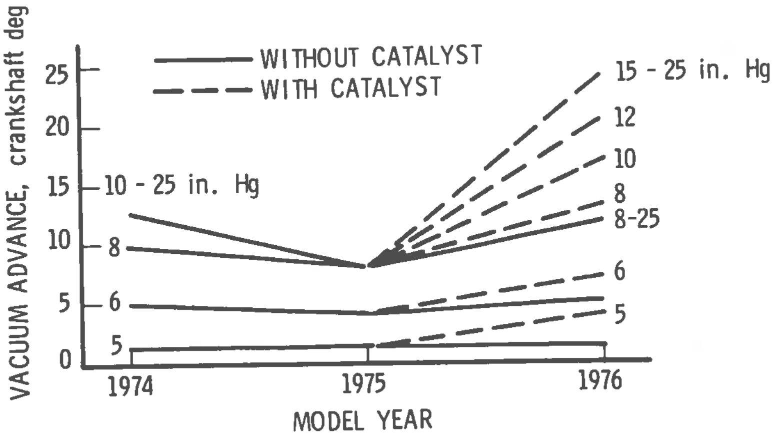


FIGURE 4-37. AVERAGE VACUUM SPARK ADVANCE SCHEDULE: FORD 2. 3-LITER ENGINE WITH AUTOMATIC TRANSMISSION; 49-STATES CALIBRATION

control valve is attached to the carburetor spacer, permitting flow of exhaust gas from the engine crossover through the valve and spacer into the intake manifold. This valve uses a pintle protruding through the valve seal for improved flow control relative to the simple poppet-type valve employed in other engines. The flow rate through the valve is controlled by the pintle outer diameter, the seal inner diameter, and the pressure differential between the exhaust and intake manifold of the engine.

In most 2.3-liter installations, the vacuum signal which operates the EGR valve originates at the carburetor venturi. The signal is controlled by a water temperature sensing valve (EGR-PVS) which is closed below $125^{o}F$ and fully open at $138^{o}F$. The relatively weak carburetor signal is amplified by the vacuum amplifier to improve the EGR flow control for better NO_x control and vehicle driveability. In some cases, the amplifier has a 1-2 in. Hg output bias for improved system response. The amplifier system incorporates a relief valve which "dumps" the output EGR signal of the amplifier whenever the venturi vacuum is equal to or greater than intake manifold vacuum. This override function permits closing of the EGR valve near WOT to restore the full power output capability of the engine.

Several of the 1975 and 1976 certification vehicles incorporate additional EGR system components, including an amplifier vacuum check valve and an EGR delay valve. The check valve is designed to maintain an adequate vacuum supply for the amplifier regardless of the variation in engine manifold vacuum, hence providing better EGR modulation and improved NO_x control. The EGR delay valve is installed in the EGR valve vacuum line for the purpose of delaying the opening of the EGR valve and preventing engine stumble caused by sudden changes in the EGR flow rate.

Most of the 1976 model 49-states 2.3-liter engines are equipped with a ported vacuum-operated EGR system which functions without the use of a vacuum amplifier.

Ford has considered a number of additional EGR system components for use in selected 1975 and 1976 engine families, including an air cleaner mounted temperature/vacuum switch (TVS), a high-speed EGR modulator, a vacuum bias control system, and a backpressure transducer. While some of these devices have been introduced through running changes after completion of the original series of EPA certification tests, none of these components have been employed in the certification vehicles considered in this study.

4.3.2.6.2 EGR Valve Calibration

The EGR valve calibration data for the certification vehicles considered here are presented in Tables 4-16 and 4-17, which list the signal pressure required for valve opening and the volume flow rate through the valve corresponding to an applied signal vacuum of 12-in. Hg. While the available information is not sufficient to determine the EGR flow to engine air flow ratio at individual engine operating points, the data are adequate to draw a number of qualitative conclusions. For instance, for each model year, the EGR flow used in the California vehicles is substantially higher than for the corresponding 49-states vehicles, to meet the more stringent California NO_x standards. As further discussed in Section 4.3.2.10, the generally lower fuel economy of the California vehicles is partly attributed to the higher EGR flows used in these vehicles. In general, the vehicles with automatic transmission have higher EGR rates, reflecting the higher engine power output required to compensate for the lower efficiency of the automatic transmission.

While the Federal NO_x standards remained essentially unchanged between 1974 and 1976, the EGR flow of the 1976 49-states vehicles listed in Tables 4-16 and 4-17 is lower than in 1974. This reduction is the result of the Ford effort to optimize the EGR system and provide adequate NO_x control consistent with acceptable vehicle driveability and fuel economy.

4.3.2.7 Thermactor Exhaust Emission Control System

The Ford thermactor exhaust emission control system is used in all 1974-1976 vehicles equipped with the 2.3-liter engine. This system is designed to reduce the emissions of HC and CO by injecting air directly into the engine exhaust ports to promote the oxidation of these species before the exhaust gases are admitted to atmosphere. A belt-driven two-vane positive displacement air pump provides the air which is manifolded through small tubes and directed to impinge on the exhaust valves. The air pump pulley drive ratio is 0.95:1, and the minimum flow rate supplied by the pump at 1000 rpm is 7.2 cfm.

The thermactor system incorporates a check valve and an exhaust bypass valve (Table 4-14 and 4-15). The check valve which is located in the air supply line between the bypass valve and the injection ports permits thermactor air to enter the exhaust manifold but prevents reverse flow of exhaust gases in the event of improper system operation. The air bypass valve (ABPV) is designed to prevent engine backfire during deceleration when larger amounts of unburned gases are discharged into the exhaust manifold and are rapidly burned with the injected air. In the 1974 system, the sudden rise in intake manifold vacuum during deceleration overcomes the spring pressure of the valve diaphragm and opens the valve. Air is then diverted to atmosphere for a brief period until the vacuum is again equalized on both sides of the diaphragm through a small orifice in the diaphragm. While the same bypass valve is employed in most 1975 and 1976 engines, a number of the catalyst-equipped vehicles listed in Tables 4-14 and 4-15 incorporates a modified system consisting of a bypass valve and a vacuum differential valve (VDV) located between the bypass valve and the vacuum source. During normal operation, the intake manifold vacuum applied to the valve through the VDV holds the valve in the open position, allowing air to be injected into the exhaust manifold. Conversely, when the intake manifold vacuum suddenly rises during deceleration, a vacuum condition is created under the VDV diaphragm, pulling the vacuum dump valve disk down and effectively interrupting the vacuum to the air bypass valve by diverting the vacuum source to atmosphere. This causes diversion of the air flow until the vacuum equalizes on both sides of the VDV diaphragm through the small timing orifice in the diaphragm.

All catalyst-equipped 2.3-liter engines incorporate a cold engine thermactor lockout system, consisting of a temperature switch in the air cleaner and a solenoid valve located in the vacuum line between the intake manifold and the air bypass valve. When the engine is cold, the switch is activated, closing the solenoid circuit and diverting the secondary air to atmosphere. Two of the 1976 California vehicles are equipped with a floor pan mounted thermal switch which opens at a temperature of about 240°F and interrupts the manifold vacuum to the VDV and ABPV. As a result, the air flow from the pump is diverted, preventing excessive catalyst and underbody temperatures.

The power required to operate the pump is low and has little impact on the fuel economy of the vehicle. Typically, the pump power varies between about 0.2 HP at 1000 rpm to about 1 HP at 3000 rpm (Ref. 4-36).

4.3.2.8 Catalytic Converter

All Ford 1975 and 1976 model year automobiles certified for sale in California and many of the Ford 1975/76 49-states vehicles are equipped with one or two catalytic converter units installed in the exhaust system between the engine and the muffler. The converter consists of a structural shell and appropriate devices to contain the monolothic substrate, which is coated with a precious metal catalyst material. Prior to the application of the active catalyst material, a highly porous proprietary washcoat is deposited on the substrate surface to increase the effective surface area of the unit.

The catalyst system requires the use of secondary air provided by the thermactor system to maintain an adequate oxygen concentration in the exhaust gas for efficient oxidation of HC and CO in the catalyst.

The substrate used in the 2.3-liter engine has a diameter of 3.66 inches and a length of 6 inches. The active material consists of either 67 percent platinum and 33 percent palladium or 93 percent platinum and 7 percent other materials. The respective precious metal loadings of the substrate are 0.06 and 0.05 troy oz.

While the catalyst has no direct bearing on fuel economy, it permits the use of more optimum distributor and carburetor calibrations; hence, it provides a potential for substantial fuel economy improvements.

4.3.2.9 Crankcase and Evaporative Emission Control

All 2.3-liter engines are equipped with a closed crankcase emission control system and an evaporative emission control system. These systems are functionally identical to the configurations described in Section 3.

4.3.2.10 Fuel Economy and Emissions

The city and highway fuel economy and emission data of the 2.3-liter certification vehicles considered in this study are listed in Tables 4-16 and 4-17 for automatic and manual transmissions, respectively (Refs. 4-15 through 4-19). While the fuel economy is primarily affected by vehicle weight, engine size, rear axle ratio, transmission type, and component calibration, a number of other factors impact fuel economy, including tire size, gear ratios, vehicle drag, and accessories. Since the latter factors have remained largely unchanged for the vehicles and model years considered here, these factors have been eliminated from further consideration in the following discussion.

In an attempt to isolate the effects of engine modifications and component adjustments on city and highway fuel economy, the data listed in Tables 4-16 and 4-17 have been normalized to a common vehicle inertia weight of 3000 pounds and a common rear axle ratio of 3.40, using sensitivity coefficients derived from the data presented by Malliaries, et al. (Refs. 4-51 and 4-52). The normalization method is described in Section 3.

The average city fuel economy of the certification vehicles with automatic transmission, normalized to an inertia weight of 3000 pounds and a rear axle ratio of 3.40, is presented in Figure 4-38 as a function of model year. As discussed in Section 3, the fuel economy data listed in Table 4-14 for the 1974 certification vehicles have been increased by 5 percent to account for the different test procedures used in 1974 and 1975.

As illustrated in Figure 4-38, the city fuel economy has remained nearly constant between 1974 and 1975 although the use of a catalyst in the 1975 California vehicles should have enabled Ford to achieve better fuel economy by properly adjusting the carburetor, distributor, and EGR system calibrations. Since the air/fuel ratio (Tables 4-14 and 4-15) and the centrifugal and vacuum advance schedules (Figures 4-36 and 4-37) used in the 49-states vehicles have remained essentially unchanged between 1974 and 1975, the slight improvement in fuel economy of the 1975 vehicles without catalyst might be attributable to the lower EGR flows used in 1975.

The catalyst-equipped 1976 model year 49-states vehicles with automatic transmission show considerably higher fuel economy than the 1975 non-catalyst vehicles. This improvement is primarily attributed to the substantially higher centrifugal and vacuum spark advance settings used in 1976, particularly in the low speed/low load regime (Figures 4-36 and 4-37). For instance, for an engine operating point corresponding to 15-in. Hg spark port vacuum and an engine speed of 2000 rpm, the combined centrifugal and vacuum advance of the average 49-states 1976 vehicle listed in Table 4-14 is 45 deg, compared with about 26 deg in 1975. Since spark advance is generally accompanied by higher NO_x and HC emissions, Ford has increased the EGR flow,

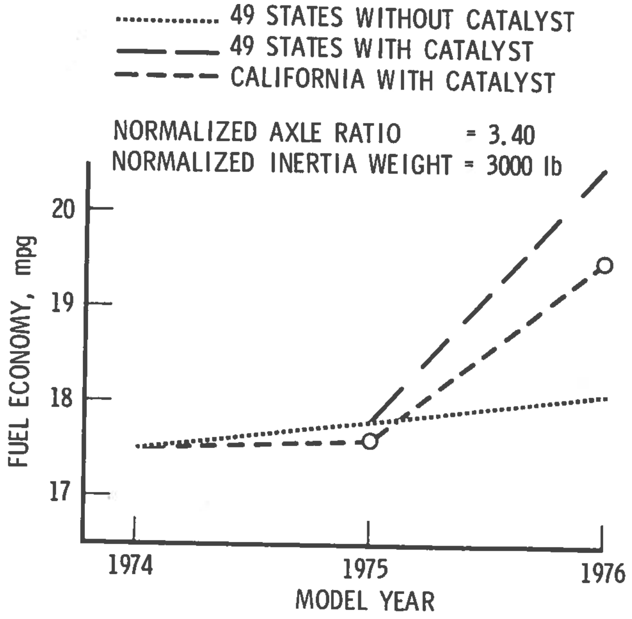


FIGURE 4-38. NORMALIZED AVERAGE CITY FUEL ECONOMY: FORD 2.3-LITER CERTIFICATION VEHICLES WITH AUTOMATIC TRANSMISSION

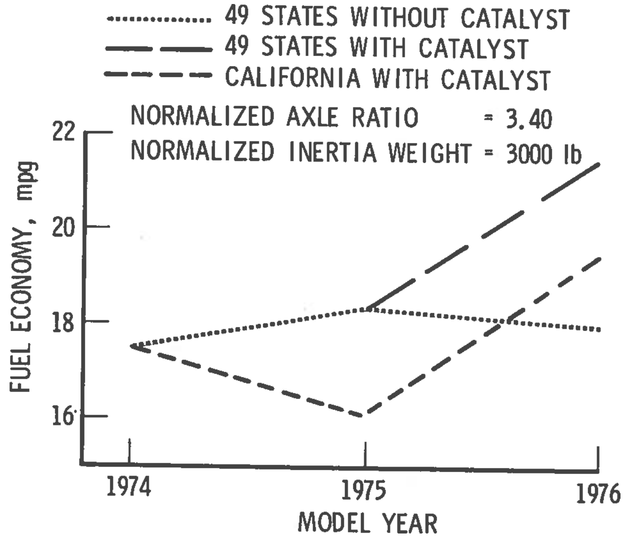


FIGURE 4-39. NORMALIZED AVERAGE CITY FUEL ECONOMY: FORD 2.3-LITER CERTIFICATION VEHICLES WITH MANUAL TRANSMISSION

in 1976, and reduced the air/fuel mixture ratios in the part-load regime in order to meet the 1976 Federal emission standards. However, considering the relatively low HC and NO_x emissions of the 1976 49-states vehicles, it appears that additional improvements in fuel economy might be realized through the optimization of spark timing, air/fuel mixture ratio, and EGR flow schedules, and the application of more efficient catalysts. As shown in Tables 4-16 and 4-17, the average HC, CO, and NO_x emissions of the 1976 model 49-states vehicles with automatic transmission are only about 46, 40, and 68 percent of the respective Federal standards.

Similar trends are observed for the California vehicles although the fuel economy of these vehicles is generally lower than for the 49-states configurations. This loss in economy is attributed to the lower spark advance, lower air/fuel mixture ratio and higher EGR flows used in these vehicles to meet the more stringent California emission standards. For example, at the 2000 rpm and 15-in. Hg spark port vacuum setting, the total spark advance of the California calibration is only 39 deg compared with 45 deg for the 49-states calibration at the same operating point. While the average HC and CO emissions of the 1976 California vehicles are higher than in 1975, there appears to be an adequate margin for further optimization of these vehicles, considering the parameters discussed above for the 49-states vehicles.

The normalized city fuel economy characteristics of the vehicles with manual transmission are presented in Figure 4-39. Except for the California calibration, which shows a decline in fuel economy in 1975, the trends are similar to those discussed for the automatic transmission. The observed decline is difficult to rationalize because both spark advance and air/fuel ratio have remained near the 1974 levels, while the EGR flow has been reduced; this should have resulted in some improvement in fuel economy. In view of the small data sample, no further attempts are made to resolve the apparent discrepancies.

In general, the city fuel economy of the 49-states vehicles with manual transmission tends to be slightly better than for the automatic transmission configurations. Conversely, the California vehicles show similar fuel economy for both transmission types in 1974 and 1976 and a 10 percent loss in fuel economy for the manual transmission in 1975 relative to 1974.

The highway fuel economy of the 1975 and 1976 certification vehicles is listed also in Tables 4-16 and 4-17. While the trends are similar to the city fuel economy characteristics discussed, the highway economy of the 49-states vehicles with manual transmission is generally between 8 and 15 percent higher than for the automatic transmission. However, the 1975 California calibration with manual transmission shows low fuel economy, consistent with the previously noted trend in city fuel economy.

4. 3. 3 Ford 2. 8-Liter Engine

4. 3. 3. 1 Engine Design Features

The 2. 8-liter engine is a compact V-6 design of modern light iron construction, incorporating a precision molded cast iron crankshaft supported by four replaceable copper alloy bearings. Except for the 60-deg block inclination, the engine is similar to the Ford V-8 engines in both construction and serviceability. Important engine and component design and operating specifications are listed in Table 4-18. (Refs. 4-43 through 4-50).

4. 3. 3. 2 Engine Modifications

Since its introduction in 1974, the basic design of the engine, including the valve configuration and timing, combustion chamber size and shape, and compression ratio, has remained unchanged. However, a number of component and component calibration modifications and additions has been incorporated, in 1975, to meet the Federal and California emission regulations. Additional modifications were implemented in 1976 to improve the vehicle fuel consumption characteristics over both city and highway driving cycles.

4. 3. 3. 3 Air Intake System

The air intake systems used in the 1974, 1975, and 1976 model year 2. 8-liter engines are similar to the systems described in Section 4. 3. 2. 3 for the 2. 3-liter engine. The 1974 system includes an exhaust manifold heater, a vacuum motor-operated duct and valve assembly, and a bimetallic intake air temperature sensor. As shown in Tables 4-19 and 4-20, all 1975 and 1976 certification vehicles considered in this study incorporate a cold weather modulator which is designed to prevent sudden cooling of the engine intake air during warmup and at low ambient temperatures.

TABLE 4-18. ENGINE SPECIFICATIONS: FORD 2.8-LITER (171-CID) ENGINE

Engine Parameter	Model Year					
	1976		1975		1974	
	49 States	California	49 States	California	49 States	California
No. of Cylinders	6		6		6	
Bore, in.	3.66		3.66		3.66	
Stroke, in.	2.70		2.70		2.70	
Displacement, cu in.	170.8		170.8		170.8	
Surface/Volume, 1/in.	8.7		8.7		8.7	
Compression Ratio[a]	8.2		8.2		8.2	
Cylinder Head Type	OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	103 at 4400		-		105 at 4600	
Torque, ft-lb, at Engine Speed, rpm	149 at 2800		-		140 at 3200	
Exhaust System Type	Single		Single			
Combustion Chamber Configuration	Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.57		1.57		1.563	
Intake Valve Lift, in.	0.359		0.359		0.359	
Exhaust Valve Diameter, in.	1.27		1.27		1.276	
Exhaust Valve Lift, in.	0.357		0.357		0.357	
Intake Valve Opens, deg BTC	20		20		20	
Intake Valve Closes, deg ABC	56		56		56	
Intake Valve Duration, deg	256		256		256	
Exhaust Valve Opens, deg BBC	62		62		62	
Exhaust Valve Closes, deg ATC	14		14		14	
Exhaust Valve Duration, deg	256		256		256	
Valve Overlap, deg	0.193		0.193		0.193	
Distributor Type	Breakerless		Breakerless		Breaker point	
Basic Ignition Advance, deg BTC[b]	8-12 (A) 8-10 (M)	6-10 (A) 8 (M)	10 (A) 6 (M)	8 (A) 6 (M)	12	
Idle Speed, rpm[b]	700 (A) 850 (M)	700-800 (A) 850-950 (M)	700 (A) 850 (M)	650 (A) 750 (M)		
Fast Idle Speed, rpm	1600 to 1700	1600 to 1700	1600		1600	
Fuel System Type	2-V downdraft Ford 2150		2-V downdraft Ford 2150		2-V downdraft Holley 5200	
Fuel Metering Method	Fixed orifice		Fixed orifice		Fixed orifice	
Enrichment Method	Vacuum-actuated power valve		Vacuum-actuated power valve		Vacuum-actuated power valve	
Choke Type	Automatic electric assist		Automatic electric assist		Automatic electric assist	
Carburetor Venturi Diameter, in.	1.08		1.08		1.02 (primary) 1.06 (secondary)	
Carburetor Maximum Air Flow, cfm, at Vacuum, in. Hg	22.9 lb/min at 3-in. Hg		22.9 lb/min at 3-in. Hg		233 cfm	
Emission Control Systems	EGR AIR CAT PCV EVAP		EGR AIR CAT PCV EVAP		EGR AIR PCV EVAP	

[a] No manual transmission

[b] A = automatic transmission; M = manual transmission

TABLE 4-19. EMISSION CONTROL SYSTEMS AND DEVICES: FORD 2.8-LITER ENGINE WITH AUTOMATIC TRANSMISSION

Engine/Vehicle System	Model Year And Certification Standard[a]													
	1976 49-States				1976 California			1975 49-States		1975 California		1974 49-States	1974 California	
Vehicle Model	Pinto	Bobcat	Pinto	Capri	Capri	Pinto	Pinto	Pinto	Mustang	Pinto	Mustang	Mustang	Mustang	Capri
Certification Calibration	6-4G-R21	6-4G-R21	5-4G-R40	5-4J-R15	5-4R-R15	6-4N-R23	6-4N-R23	5-4G-R2	5-4G-R2	5-4N-R1	5-4N-R1	4-4A-R16	4-4U-R11	4-4Y-R4
Vehicle Inertia Weight, lb	3500	3000	3500	3000	3000	3000	3500	3500	3500	3500	3500	3500	3500	3000
Rear Axle Ratio	3.00	3.40	3.00	3.09	3.22	3.00	3.40	3.40	3.55	3.40	3.55	3.55	3.55	3.22
Emission Control Systems														
Air Injection	x	x	x	x	x	x	x	x	x	x	x	x	x	x
EGR	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Oxidation Catalyst	x	x	x	x	x	x	x	x	x	x	x			
Crankcase Ventilation	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Evaporative Control	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Emission Control Devices														
Water-Heated Choke												x	x	x
Hot Air-Heated Choke	x	x	x	x	x	x	x	x	x	x	x			
Electric Assist Choke	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Hot Idle Compensator														
Fuel Deceleration Valve	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Bimetal Sensor	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Duct and Valve	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Cold Weather Modulator	x	x	x	x	x	x	x	x	x	x	x			
EGR Valve[b]	Tap stem	Tap stem	Tap stem	Poppet	Tap stem	Tap stem	Tap stem	Poppet	Poppet	Tap stem	Tap stem	Poppet	Poppet	Poppet
EGR Venturi Vacuum Amplifier												Biased	Unbiased	Biased
EGR Vacuum Control Valve			x	x	x	x	x	x	x	x	x		x	
Distributor Vacuum Control Valve	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spark Delay Valve			x		x			x	x	x	x	x	x	x
Thermactor Air Pump	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Thermactor Air Bypass Valve	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Thermactor Vacuum Differential Valve			x	x	x	x	x	x	x	x	x			
Thermactor Idle Dump Valve	x	x				x								
Thermactor Retard Delay Valve	x	x				x								
Cold Lockout Air Cleaner TAV Switch[c]			x	x	x			x	x	x	x			
Floorpan Mounted Thermal Switch				x	x									
Fuel Deceleration Valve Low-Speed Modulator									x					
Exhaust Heat Control Valve/Vacuum Motor			x					x	x	x	x			
Air Cleaner Vacuum Control (TVS)[d]	x	x				x	x							
EGR Vacuum Restrictor				x	x									
Cold Start Spark Advance				x										
Cold Temperature Spark Retard				x	x									

[a] x indicates system is used in model year shown, [b] Tap stem = tapered stem, [c] Temperature-activated valve, [d] Thermal vacuum switch

TABLE 4-20. EMISSION CONTROL SYSTEMS AND DEVICES: FORD 2.8-LITER ENGINE WITH MANUAL TRANSMISSION

Engine/Vehicle System	Model Year And Certification Standard[a]										
	1976 49-States			1976 California		1975 49-States		1975 California		1974 49-States & California	
Vehicle Model	Mustang	Mustang	Capri	Capri	Mustang	Mustang	Mustang	Mustang	Mustang	Mustang	Mustang
Certification Calibration	6-3H-R21	6-3H-R21	5-3J-R15	5-3R-R15	6-3N-R21	5-3H-R0	5-3H-R0	5-3N-R0	5-3N-R0	4-4D-R11	4-4V-R3
Vehicle Inertia Weight, lb	3500	3500	3000	3000	3500	3500	3500	3500	3500	3500	3500
Rear Axle Ratio	3.55	3.40	3.09	3.22	3.55	3.55	3.55	3.55	3.55	3.55	3.55
Emission Control Systems											
Air Injection	x	x	x	x	x	x	x	x	x	x	x
EGR	x	x	x	x	x	x	x	x	x	x	x
Oxidation Catalyst	x	x	x	x	x	x	x	x	x		
Crankcase Ventilation	x	x	x	x	x	x	x	x	x	x	x
Evaporative Control	x	x	x	x	x	x	x	x	x	x	x
Emission Control Devices											
Water-Heated Choke										x	x
Hot Air Heated Choke	x	x	x	x	x	x	x	x	x		
Electric Assist Choke	x	x	x	x	x	x	x	x	x	x	x
Hot Idle Compensator					x						
Fuel Deceleration Valve	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Bimetal Sensor	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Duct and Valve	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Cold Weather Modulator	x	x	x	x	x	x	x	x	x		
EGR Valve[b]	Tap stem	Tap stem	Poppet	Tap stem	Poppet	Poppet	Poppet	Tap stem	Tap stem	Poppet Unbiased	Poppet Biased
EGR Venturi Vacuum Amplifier											
EGR Vacuum Control Valve			x	x	x	x	x	x	x	x	
Distributor Vacuum Control Valve				x	x	x	x	x	x	x	x
Spark Delay Valve			x	x	x	x	x	x	x	x	x
Thermactor Air Pump	x	x	x	x	x	x	x	x	x	x	x
Thermactor Air Bypass Valve	x	x	x	x	x	x	x	x	x	x	x
Thermactor Vacuum Differential Valve			x	x		x	x	x	x		
Thermactor Idle Dump Valve	x	x			x						
Thermactor Retard Delay Valve	x	x			x						
Cold Lockout Air Cleaner TAV Switch[c]			x	x		x	x	x	x		
Floorpan Mounted Thermal Switch				x							
Fuel Deceleration Valve Low-Speed Modulator						x	x	x	x		
Exhaust Heat Control Valve/Vacuum Motor			x			x	x	x	x		
Air Cleaner Vacuum Control (TVS)[d]	x	x			x						
EGR Vacuum Restrictor			x	x							
Cold Start Spark Advance			x								
Cold Temperature Spark Retard			x	x							
EGR Backpressure Transducer					x						

[a] X indicates system is used in model year shown, [b] Tap stem = tapered stem, [c] Temperature-activated valve, [d] Thermal vacuum switch

The 1975 engines are equipped with an intake manifold vacuum operated exhaust heat control valve, installed in the exhaust manifold. During a cold start the valve is closed, forcing exhaust gas through a flow passage in the intake manifold. This enhances the fuel vaporization process and permits the use of leaner air/fuel mixtures, resulting in lower HC and CO emissions and better fuel economy. When the coolant temperature reaches about 130°F, the vacuum supply to the vacuum motor is interrupted by a temperature switch, and the heat control valve opens.

4.3.3.4 Carburetor

4.3.3.4.1 Design Features

All 1975 and 1976 model year 2.8-liter engines are equipped with a Motorcraft 2150-2V carburetor, consisting of a main and booster venturi, power enrichment system, accelerator pump, and heated choke system. The main venturi and accelerator pump systems are similar to those employed in the 2.3-liter engine and discussed in Section 4.3.2.3. The booster venturi contains a number of high-speed bleed orifices along with a mechanical high-speed bleed control system. This system consists of a mechanical lift rod which actuates a set of reverse tapered metering rods located in the high-speed bleed orifices to provide better control of the air/fuel mixture in the booster venturi at high speed, as well as improved low-speed response.

The enrichment system is designed to provide additional fuel under high-load operation of the engine. In this design, fuel is drawn from the fuel bowl through a set of metering orifices and into the air flow through bleed orifices located in the upper body air horn.

As indicated in Tables 4-19 and 4-20, an automatic, hot air heated choke with electric assist is used in 1975 and 1976. The hot air originates at the exhaust manifold and is ducted through the choke housing to accelerate choke opening by heating the bimetallic spring which controls the choke position. Additional HC and CO control during engine cold start is achieved by means of an electric assist heater located inside the choke housing. As discussed in Section 4.3.2.3, this heater accelerates the warmup process of the bimetallic spring and limits the choke action to about 1-2 minutes for ambient temperatures above 60°F.

The 1974 model 2.8-liter engine incorporates a Holley 5200-2V carburetor in conjunction with a water-heated choke system. The functional characteristics of this unit are described in Section 4.2.2.3.

All 2.8-liter engines are equipped with a fuel deceleration metering system consisting of a fuel deceleration valve (FDV), a metered pickup orifice in the fuel bowl, and a series of fuel/air mixing orifices and bleeds. The FDV is designed to provide a rich air/fuel mixture to the engine intake for added HC and CO control during vehicle deceleration.

The 1975 engine with manual transmission incorporates a deceleration valve low-speed modulator which consists of a speed sensor, electronic module, and solenoid vacuum control valve. The speed sensor is driven by the speedometer cable and provides a signal to the electronic module which, in turn, controls the position of the solenoid valve. When vehicle speed drops below the module trigger speed, the module output signal closes the solenoid control valve and deactivates the FDV by interrupting the manifold vacuum normally supplied to this valve.

Some 1976 engines are equipped with a hot idle compensator, which alleviates hot fuel handling problems. This unit is functionally identical to the design used in the 2.3-liter engine.

4.3.3.4.2 Carburetor Calibration

The carburetor calibration data are presented in Tables 4-21, and 4-22 for automatic and manual transmission, respectively, showing the air/fuel ratio at idle, off idle, part-throttle, and WOT (Refs. 4-43 through 4-48). With few exceptions, the air/fuel ratio was leaned out in 1975 relative to 1974, followed by generally lower air/fuel ratios in 1976. In the main, the California calibrations are richer than the 49-states calibrations, particularly at part-load. The air/fuel ratio tolerances have remained nearly constant between 1974 and 1976 and are comparable to the tolerance bands shown in Figure 4-34 for the 2.3-liter engine.

According to Ford (Ref. 4-53), the air/fuel ratio distribution for each model year has been selected in conjunction with optimum spark timing and EGR flow calibrations and the addition of a catalyst, in 1975 and 1976, to provide an acceptable compromise between fuel economy and driveability consistent with prevailing emission regulations.

TABLE 4-21. CERTIFICATION CALIBRATION DATA: FORD 2.8-LITER ENGINE WITH AUTOMATIC TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard													
	1976 49 States			1976 California				1975 49 States		1975 California		1974 49 States	1974 California	
Vehicle Model	P[c]	B[d]	P[c]	Ca[b]	Ca[b]	P[c]	P[c]	P[c]	Mu[a]	P[c]	Mu[a]	Mu[a]	Mu[a]	Ca[b]
Certification Calibration	6-4G -R21	6-4G -R21	5-4G -R40	5-4J -R15	5-4R -R15	6-4N -R23	6-4N -R23	5-4G -R2	5-4G -R2	5-4N -R1	5-4N -R1	4-4A -R16	4-4U -R11	4-4Y -R4
Vehicle Inertia Weight, lb	3500	3000	3500	3000	3000	3000	3500	3500	3500	3500	3500	3500	3500	3000
Rear Axle Ratio	3.00	3.40	3.00	3.09	3.22	3.00	3.40	3.40	3.55	3.40	3.55	3.55	3.55	3.22
Catalyst	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Carburetor Calibration, A/F														
Idle	12.0	12.0	13.5	12.9	12.9	13.0	13.0	14.7	14.7	13.6	13.6	13.1	13.1	13.1
Off Idle	13.4	13.4	15.1	13.5	13.5	14.8	14.8	13.8	13.8	14.6	14.6	13.9	13.9	13.0
Part Throttle	15.1	15.1	15.4	15.1	15.3	15.0	15.0	16.9	16.9	15.4	15.4	16.2	16.2	14.9
WOT	14.6	14.6	13.5	15.0	15.0	14.7	14.7	14.5	14.5	14.7	14.7	13.1	13.1	13.0
Basic Timing, crankshaft deg BTC	12	12	8	10	10	6	6	10	10	8	8	12	12	12
Centrifugal Advance, crankshaft deg														
1000 rpm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1500 rpm	4	4	3	4	4	4	4	4	4	5	5	5	5	5
2000 rpm	10.5	10.5	11	10.5	10.5	10.5	10.5	9	9	9	9	9	9	9
3000 rpm	16	16	16	16	16	16	16	17	17	16.5	16.5	16.5	16.5	16.5
4000 rpm	22	22	21.5	21.5	21.5	21.5	21.5	17.5	17.5	17	17	18	18	18
5000 rpm	21	21	21	21	21	21	21	16	16	16	16	18	18	18
Vacuum Advance, crankshaft deg														
5 in. Hg	5	5	2	2	2	1.5	1.5	2.5	2.5	2	2	0	0	0
6 in. Hg	8	8	4	4	4	3.5	3.5	4	4	4	4	4	4	4
8 in. Hg	15	15	9	9	9	6	6	6	6	6	6	6	6	6
10 in. Hg	18	18	12	12	12	6	6	6	6	6	6	6	6	6
12 in. Hg	18	18	12	12	12	6	6	6	6	6	6	6	6	6
15 in. Hg	18	18	12	12	12	6	6	6	6	6	6	6	6	6
20 in. Hg	18	18	12	12	12	6	6	6	6	6	6	6	6	6
EGR Valve Calibration														
Signal Pressure To Open, in. Hg	2.0	2.0	2.0	2.9	2.5	3.0	3.0	2.0	2.0	2.0	2.0	2.9	2.7	2.7
Flow at 12-in. Hg, cfm	13.2	13.2	13.3	8.6	22.4	11.2	11.2	10.9	10.9	20	20	10.9	18.7	18.7
Fuel Economy, mpg[e]														
City	17	18	17	17	18	16	15	13	16	13	14	15.7	13.7	16.6
Highway	24	23	22	26	24	22	20	20	20	20	21	-	-	-
Exhaust Emissions, g/m														
HC	1.2	1.3	1.1	1.1	0.6	0.8	0.8	0.9	0.7	0.5	0.6	3.1[f]	3.0[f]	3.1[f]
CO	9	9	11	14	8	8	7	8	9	6	4	38[f]	35[f]	33[f]
NO_x	2.6	1.9	2.1	1.6	1.0	1.1	1.4	2.5	1.6	1.4	1.7	2.1[f]	1.7[f]	1.6[f]

[a] Mustang
[b] Capri
[c] Pinto
[d] Bobcat
[e] 1975 FTP
[f] 1972 FTP

TABLE 4-22. CERTIFICATION CALIBRATION DATA: FORD 2.8-LITER ENGINE WITH MANUAL TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard										
	1976 49 States			1976 California		1975 49 States		1975 California		1974 49 States	1974 Calif
Vehicle Model	MU[a]	MU[a]	Ca[b]	Ca[b]	P[c]	MU[a]	MU[a]	MU[a]	MU[a]	MU[a]	MU[a]
Certification Calibration	6-3H -R21	6-3H -R21	5-3J -R15	5-3R -R15	6-4N -R21	5-3H -R0	5-3H -R0	5-3N -R0	5-3N -R0	4-4D -R11	4-4V -R3
Vehicle Inertia Weight, lb	3500	3500	3000	3000	3500	3500	3500	3500	3500	3500	3500
Rear Axle Ratio	3.55	3.40	3.09	3.22	3.55	3.55	3.55	3.55	3.55	3.55	3.55
Catalyst	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Carburetor Calibration, A/F											
Idle	12.9	12.9	13.0	12.9	12.5	12.8	12.8	13.0	13.0	13.1	13.2
Off Idle	12.9	12.9	13.0	12.8	13.3	16.8	16.8	14.8	14.8	13.9	13.1
Part Throttle	15.8	15.8	15.1	15.2	15.7	16.8	16.8	15.4	15.4	16.2	15.0
WOT	15.1	15.1	14.8	14.7	15.1	14.3	14.3	13.8	13.8	13.1	13.0
Basic Timing, crankshaft deg BTC	10	10	8	8	8	6	6	6	6	12	12
Centrifugal Advance, crankshaft deg											
1000 rpm	0	0	0	0	0	0	0	0	0	0	0
1500 rpm	4	4	4	4	6	4	4	5	5	5	5
2000 rpm	12	12	10.5	10.5	13	9	9	9	9	9	9
3000 rpm	15	15	16	16	15.5	17	17	16.5	16.5	17	17
4000 rpm	18	18	21.5	21.5	18	17.5	17.5	17	17	18	18
5000 rpm	17	17	21	21	17	16	16	16	16	18	18
Vacuum Advance, crankshaft deg											
5 in. Hg	1	1	5	5	1	2.5	2.5	2	2	0	0
6 in. Hg	3.5	3.5	8	8.5	4	4	4	4	4	4	4
8 in. Hg	9	9	15	14.5	9	6	6	6	6	6	6
10 in. Hg	14	14	18	18	12	6	6	6	6	6	6
12 in. Hg	18	18	18	18	12	6	6	6	6	6	6
15 in. Hg	18	18	18	18	12	6	6	6	6	6	6
20 in. Hg	18	18	18	18	12	6	6	6	6	6	6
EGR Valve Calibration											
Signal Pressure To Open, in. Hg	3.0	3.0	2.9	3.0	1.7	2.9	2.9	2.5	2.5	2.7	2.9
Flow at 12-in. Hg, cfm	11.2	11.2	4.2	11.2	(2)	4.2	4.2	24	24	2.9	6.2
Fuel Economy, mpg											
City	17	16	18	16	15	15	15	15	15	18.2	-
Highway	25	24	28	27	24	23	24	23	24	-	-
Exhaust Emissions, g/m											
HC	1.3	1.3	1.0	0.8	0.8	0.6	0.8	0.7	0.6	2.8[e]	2.1[e]
CO	11	10	8	7	8	6	8	7	5	23 [e]	37 [e]
NO_x	3.0	2.9	1.6	1.1	1.5	2.5	2.6	1.8	1.1	2.6[e]	1.9[e]

[a] Mustang   [b] Capri   [c] Pinto   [d] 1975 FTP   [e] 1972 FTP

4.3.3.5 Ignition System

4.3.3.5.1 Design Features

While all 1974 certification vehicles considered in Tables 4-19 through 4-22 have been equipped with a breaker-point ignition system, a breakerless solid-state system has been introduced in some 2.8-liter engines, toward the end of the 1974 model year run. This system, which has been used exclusively in 1975 and 1976, eliminates breaker-point deterioration and associated misfire and high HC emission problems. As described in Section 4.3.2.5, the Ford breakerless ignition system consists of a conventional ballast resistor and ignition switch, plus a number of new components, including the ignition coil, distributor, and solid-state electronic switching module. Spark timing control is maintained by means of conventional centrifugal and vacuum advance mechanisms.

Most of the certification vehicles listed in Tables 4-19 and 4-20 are equipped with a dual diaphragm distributor which is similar in design to that used in some 2.3-liter engines. Relative to single diaphragm configurations, this unit is controlled by two independent vacuum sources (spark port and intake manifold vacuum) and is designed to provide vacuum spark retard at idle and during vehicle deceleration as a means of reducing HC emissions. Depending upon the application, Ford uses different levels of spark retard, varying between about 2 deg for the average 1976 49-states certification vehicle with manual transmission to about 12-deg retard for the 1975 49-states and California vehicles with automatic or manual transmission.

4.3.3.5.2 Spark Timing Control Devices

Most 2.8-liter engines considered in Tables 4-19 and 4-20 incorporate a PVS valve and a SDV. Both valves are functionally identical to those previously discussed for the 2.3-liter engine (Section 4.3.2.5.2). The PVS switches the distributor vacuum source from spark port to intake manifold when coolant temperature exceeds about 225°F. The SDV valve aids in the control of HC and NO_x emissions by delaying the vacuum advance during periods of mild acceleration.

Two of the 1976 model 49-states certification vehicles are equipped with cold start spark advance (CSSA) and cold temperature spark retard control features. The cold temperature retard is used also in the 1976 California vehicles. The CSSA system incorporates a separate coolant temperature-controlled PVS valve installed in the vacuum line to the distributor and a vacuum check valve located in the line between the PVS and the intake manifold vacuum port. Below the opening temperature of the PVS (about 130°F), intake manifold vacuum is supplied to the distributor spark advance mechanism, resulting in higher spark advance in the part-load regime during engine warmup.

The cold temperature retard control system used in conjunction with the dual diaphragm distributor uses the cold lockout temperature activated vacuum (TAV) switch installed in the air cleaner to control the vacuum supply to the retard diaphragm of the distributor. Below 60°F, the TAV switch is closed, preventing the use of spark retard during deceleration and idle.

4.3.3.5.3 Spark Advance Schedules

The centrifugal and vacuum advance of the certification vehicles are listed in Tables 4-21 and 4-22 for automatic and manual transmissions, respectively (Refs. 4-43 through 4-48). As shown in Figure 4-40, the combined basic timing and centrifugal advance settings of the average 49-states vehicles with automatic transmission declined slightly between 1974 and 1975, followed by little change in 1976 except for a 5 degree increase in the advance at 4000 rpm and above. The California vehicles with automatic transmission and all vehicles with manual transmission show a reduction in the spark advance of about 5 deg in 1975 relative to 1974. In 1976, the advance of the California vehicles with automatic transmission was further reduced, except in the high-speed regime where the spark was advanced by about 4 deg. Conversely, the vehicles with manual transmission show a moderate increase in the spark advance in 1976, varying between about 2 and 5 deg.

The average vacuum advance of the 49-states certification vehicles with automatic transmission is presented in Figure 4-41, showing little change in the advance between 1974 and 1975 except at low vacuum levels (high loads). However, the vacuum advance was increased substantially in 1976, particularly in the high vacuum regime. Similar trends are observed for the 49-states and California vehicles with manual transmission. The

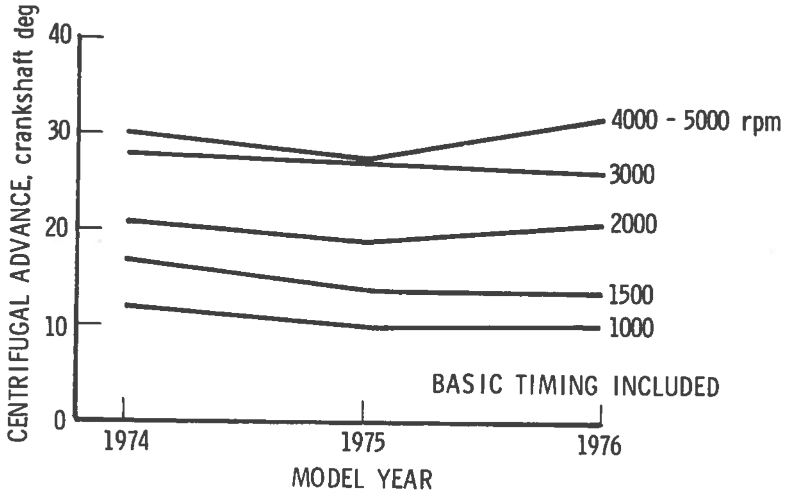


FIGURE 4-40. AVERAGE CENTRIFUGAL SPARK ADVANCE: FORD 2.8-LITER ENGINE WITH AUTOMATIC TRANSMISSION; 49-STATES CALIBRATION

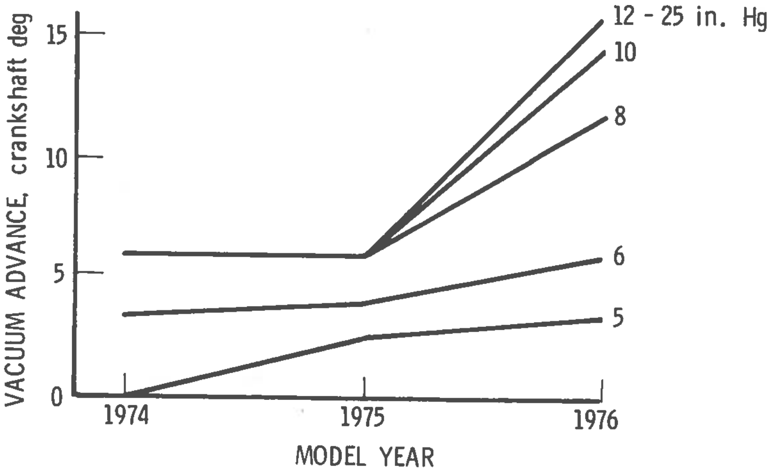


FIGURE 4-41. AVERAGE VACUUM SPARK ADVANCE: FORD 2.8-LITER ENGINE WITH AUTOMATIC TRANSMISSION; 49-STATES CALIBRATION

California calibration with automatic transmission shows little increase in vacuum advance in 1976 relative to 1975.

4.3.3.6 Exhaust Gas Recirculation

4.3.3.6.1 Design Features

As indicated in Tables 4-19 and 4-20, all 2.8-liter engines require EGR for NO_x control. The system used in 1974 is a venturi vacuum-controlled arrangement which is similar to that previously described for the 2.3-liter engine. It consists of an EGR flow control valve, a vacuum venturi amplifier, and an EGR vacuum-control valve.

While venturi vacuum control with amplifier is generally considered to be superior to port vacuum control without amplifier in terms of maintaining proportionality between EGR and engine air flows, Ford has elected to use the latter system in most 1975 and 1976 model 2.8-liter engines (Refs. 4-43 through 4-50).

The 1974 system incorporates a simple poppet-type EGR flow control valve consisting of a spring-loaded diaphragm, a poppet valve attached to the diaphragm and a restrictor orifice installed near the EGR intake port of the valve. When vacuum is applied to the spring chamber behind the diaphragm, the poppet disk is retracted from its seat, permitting EGR flow from the engine crossover, through the valve, and into the engine intake manifold. The flow is limited by the valve seat diameter and a set of orifices inserted in the mounting pad of the valve. While the same poppet valve is used in the 1975 model 49-states calibration and in some 1976 vehicles, the tapered stem-type valve is the preferred configuration for 1975 and 1976. This valve, which is similar to that used in the 2.3-liter engine, is described in Section 4.3.2.6.

Several of the 1976 vehicles incorporate an EGR vacuum restrictor in the port vacuum line which is designed to smooth out the EGR valve signal for better response of the engine to sudden changes in load.

Some 1976 engines include an exhaust backpressure transducer, either external or integral with the EGR valve diaphragm housing. This device modulates the EGR flow by varying the vacuum signal as a function of engine exhaust backpressure. It is generally agreed that backpressure-controlled EGR systems have the capability of providing better EGR control than the previously discussed venturi vacuum and ported vacuum configurations.

Instead of the ported vacuum switch (EGR - PVS) sensing coolant temperature, an air cleaner mounted intake air temperature vacuum switch (TVS) is employed in some 1976 engines. This switch is closed below 50°F but is fully open at 76°F, permitting normal EGR system operation.

4.3.3.6.2 EGR Valve Calibration

The EGR flow rates and valve opening pressures for the certification vehicles considered in this study are listed in Table 4-21. As previously noted, the available EGR data are rather limited and insufficient to establish EGR flow maps covering the whole range of engine operating conditions. However, the data are useful for drawing qualitative conclusions regarding the amount of EGR used by Ford in the various certification vehicles. As a general observation, the EGR flow in the California vehicles is substantially higher than in the 49-states calibrations, reflecting the more stringent California NO_x standards. Except for the 1975 California calibrations, the vehicles with automatic transmission are calibrated with higher EGR, to compensate for generally lower efficiency of the automatic transmission. However, on average, the NO_x emissions of the vehicles with automatic transmission are lower than for the manual transmission (Tables 4-19 and 4-20) indicating perhaps that some reduction in EGR from the current levels might be feasible for vehicles with automatic transmission and result in better fuel economy.

While the Federal and California NO_x standards have remained essentially constant during the 1974-1976 time period, the EGR flow shows significant variations. According to Ford, these modifications have been incorporated, along with changes in spark timing and carburetor air/fuel ratio, to provide an optimum system in terms of emissions, fuel economy, and vehicle driveability (Ref. 4-53).

4.3.3.7 Thermactor Exhaust Emission Control System

All 2.8-liter engines are equipped with the thermactor system, which is designed to reduce the HC and CO emissions either directly or in conjunction with a catalytic converter. As described in Section 4.3.2.7, the Ford basic thermactor system consists of an air pump, check valve, and ABPV. Other optional thermactor components used in some of the certification vehicles listed in Tables 4-19 and 4-20 incorporate a cold lockout air cleaner TAV switch, a VDV, and a floor pan-mounted thermal switch. These components are functionally identical to those previously described for the 2.3-liter engine.

A number of the 1976 vehicles employ a thermactor idle dump valve (TIV) and a thermactor retard delay valve. The TIV controls the vacuum vent of the ABPV. In case of excessive underbody temperatures which could be reached during long idle periods, the TIV causes the ABPV to open, which normally lowers the temperature of the exhaust system. The retard delay valve installed in the vacuum line between the air cleaner TAV switch and the ABPV delays thermactor air dumping during throttle fluctuations and at WOT, by delaying ported vacuum signal cutoff to the ABPV.

Depending upon the particular installation, the air pump has a pully drive ratio of 0.95 or 1.13. The unit is identical to that described in Section 4.3.2.7.

4.3.3.8 Catalytic Converter

All 1975 and 1976 model year 2.8-liter engines are equipped with a catalytic converter system of the type described in Section 4.3.2.8, consisting of two identical monolithic substrates. Each substrate has a diameter of 3.66 inches and a length of 3 inches, with a precious metal loading of 0.02-0.03 troy oz/catalyst, depending on the supplier and the platinum content of the active material.

4.3.3.9 Crankcase and Evaporative Emission Control

All 2.8-liter engines are equipped with a closed-loop crankcase emission control system and an evaporative emission control system of the type described in Section 3.

4.3.3.10 Fuel Economy and Emissions

The city and highway fuel economy of the certification vehicles is listed in Tables 4-21 and 4-22 for automatic and manual transmissions, respectively. For a better comparison of the fuel economy trends as affected by calibration changes, the data have been normalized to a common inertia weight of 3500 pounds and a rear axle ratio of 3.44, using the procedure discussed in Section 3. As shown in Figure 4-42, the normalized city fuel economy of the

49-states vehicles with automatic transmission show a decline between 1974 and 1975, followed by a substantial increase in 1976. Since the variations in spark advance (Figures 4-40 and 4-41), air/fuel ratio (Table 4-21) and EGR flow (Table 4-21) implemented in 1975 have been rather small, the observed loss in fuel economy in 1975 relative to 1974 is considered to be primarily due to test-to-test and hardware-to-hardware variabilities. Conversely, the marked improvement of the city fuel economy in 1976 is attributed to the higher part-load spark advance used in 1976. For example, for an engine speed of 2000 rpm and a spark port vacuum of 12-in. Hg, the total spark advance in 1976 is 37 deg BTC compared with 25 deg BTC in 1975. As indicated in Table 4-21, the fuel economy improvement in 1976 was accomplished at nearly constant emission levels by increasing the EGR flow rate and optimizing the total engine system, including carburetor air/fuel ratio, spark advance, and EGR system operation.

The California vehicles with automatic transmission show similar fuel economy trends. However, in this case the spark advance was increased little in 1976, and the improvement in fuel economy shown in Figure 4-42 is attributed primarily to the reduction in EGR in 1976 and the fact that the air/fuel ratio at part-load remained unchanged between 1975 and 1976.

The sharp decline in fuel economy of the manual transmission equipped vehicles in 1975 (Figure 4-43) is partly attributed to the lower spark advance and higher EGR flows used in 1975 relative to 1974. However, the modifications in these parameters are not considered to be sufficiently large to justify the observed loss in fuel economy. The fuel economy improvement of the 49-states vehicles in 1976 is attributed to higher spark advance. Since the EGR flow has been increased in these vehicles relative to 1975, the observed fuel economy improvement is slightly less than for the vehicles with automatic transmission.

While no change in fuel economy is shown in Figure 4-43 for the California vehicles equipped with manual transmission, a gain in fuel economy similar to the 49-states vehicles would have been projected on the basis of the spark advance and EGR flow modification implemented in 1976.

In the main, the highway fuel economy data presented in Tables 4-21 and 4-22 follow the city fuel economy trends and are consistent with the spark advance and EGR settings employed in the various engines. As expected,

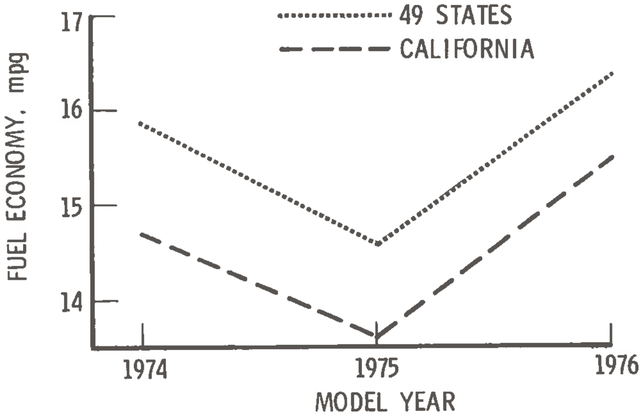


FIGURE 4-42. NORMALIZED AVERAGE CITY FUEL ECONOMY: FORD 2.8-LITER ENGINE WITH AUTOMATIC TRANSMISSION

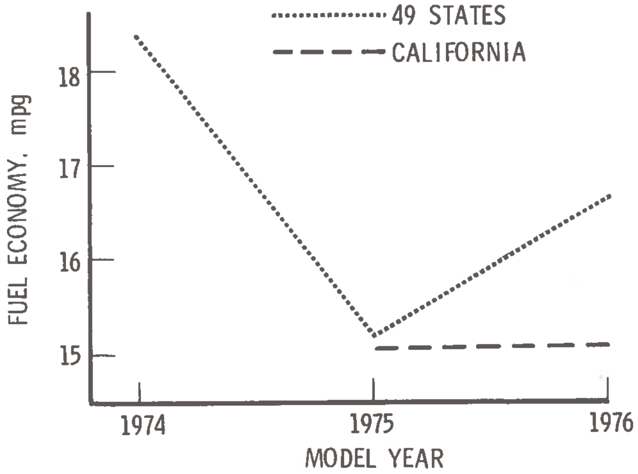


FIGURE 4-43. NORMALIZED AVERAGE CITY FUEL ECONOMY: FORD 2.8-LITER ENGINE WITH MANUAL TRANSMISSION

the highway fuel economy of the vehicles with manual transmission is about 10-15 percent higher than for the automatic transmission equipped vehicles.

4.3.4 Ford 250-CID Engine

4.3.4.1 Engine Design Features

The 250-CID engine is an inline 6-cylinder overhead valve design of lightweight cast iron construction. Since its introduction in 1969, the engine has been equipped with a positive closed-type CCV system to eliminate the emission of crankcase vapors into the atmosphere. This system is functionally identical to the design used in all other Ford engines and is described in Section 3. An evaporative emission control system was added in California in 1970 and nationwide in 1971 to minimize the emission of raw gasoline vapors from the fuel tank and carburetor. The system currently used is similar to that described in Section 3. As discussed later, a number of other engine modifications and additions have been incorporated in recent years to meet the emission standards consistent with acceptable vehicle driveability and fuel economy (Refs. 4-43 through 4-50 and 4-54).

4.3.4.2 Engine Modifications

While the basic design of the engine has remained unchanged since 1969, a number of components have been modified, including the combustion chamber and the camshaft. As shown in Table 4-23, the 1974 engine has a lower compression ratio and a slightly lower combustion chamber surface-to-volume ratio. As a result, the engine has now the capability of operating satisfactorily on 91 octane gasoline. In addition, these changes have resulted in slightly lower HC and NO_x emissions. However, the reduction in compression ratio is accompanied by a small loss in fuel economy, estimated to be about 3-4 percent based on the work by Huebner and Gasser (Ref. 4-55) and Murrell (Ref. 4-56).

While the original valve size has been retained by Ford, the valve lift, valve timing, and valve overlap have been modified in 1974 and again in 1975. The valve overlap of the 1974 engine has been increased from the original setting to provide additional NO_x control by increasing the dilution of the intake air with exhaust gas. The same valve timing and overlap settings are

TABLE 4-23. ENGINE SPECIFICATIONS: FORD 250-CID ENGINE

Engine Parameter	Model Year							
	1976		1975		1974		1969	
	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	6		6		6		6	
Bore, in.	3.68		3.68		3.68		3.68	
Stroke, in.	3.91		3.91		3.91		3.91	
Displacement, cu in.	250		250		250		250	
Surface/Volume, 1/in.	5.8		5.8		5.8		5.9	
Compression Ratio	8.0		8.0		8.0		9.1	
Cylinder Head Type	OHV		OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	78 at 2800		72 at 2900		91 at 3200		-	
Torque, ft-lb, at Engine Speed, rpm	178 at 1600		180 at 1400		190 at 1600		-	
Exhaust System Type	Single		Single		Single		Single	
Combustion Chamber Configuration	Wedge		Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.65		1.65		1.65		1.65	
Intake Valve Lift, in.[a]	0.372	0.372 (A) 0.384 (M)	0.372 (A) 0.384 (M)		0.384		0.368	
Exhaust Valve Diameter, in.	1.39		1.39		1.39		1.39	
Exhaust Valve Lift, in.[a]	0.372	0.372 (A) 0.352 (M)	0.372 (A) 0.352 (M)		0.352		0.368	
Intake Valve Opens, deg BTC[a]	18	18 (A) 26 (M)	18 (A) 26 (M)		26		10	
Intake Valve Closes, deg ABC[a]	54	54 (A) 58 (M)	54 (A) 58 (M)		58		62	
Intake Valve Duration, deg[a]	252	252 (A) 264 (M)	252 (A) 264 (M)		264		252	
Exhaust Valve Opens, deg BBC[a]	57	57 (A) 37 (M)	57 (A) 37 (M)		37		49	
Exhaust Valve Closes, deg ATC	17	17	17		17		25	
Exhaust Valve Duration, deg[a]	254	254 (A) 234 (M)	254 (A) 234 (M)		234		254	
Valve Overlap, deg in.[a]	0.220	0.220 (A) 0.543 (M)	0.220 (A) 0.543 (M)		0.543		-	
Distributor Type	Breakerless		Breakerless		Breaker point	Breakerless	Breaker point	
Basic Ignition Advance, deg BTC[a]	12 (A) 8 (M)	6-10 (A) 6 (M)	6		6		6	
Idle Speed, rpm[a]	600 (A) 850 (M)		600 (A) 800 (M)	600 (A) 850 (M)	600 (A) 750 (M)		600 (A) 750 (M)	
Fast Idle Speed, rpm	1700		1700		1700		-	
Fuel System Type	1-V downdraft Carter YFA		1-V downdraft Carter YFA		1-V downdraft Carter RBS		1-V downdraft Carter RBS	
Fuel Metering Method	Tapered rod		Tapered rod		Rod in jet		Rod in jet	
Enrichment Method	Vacuum-actuated metering rod		Vacuum-actuated metering rod		Vacuum-actuated metering rod		Vacuum-actuated metering rod	
Choke Type	Automatic electric assist		Automatic electric assist		Automatic		Automatic	
Carburetor Venturi Diameter, in.	1.31		1.31		1.38		1.44	
Carburetor Maximum Air Flow, lb/min, at Vacuum, in. Hg	14.5 lb/min at 3 in. Hg		14.5 lb/min at 3 in Hg		206 cfm		215 cfm	
Emission Control Systems	EGR AIR CAT PCV EVAP		EGR AIR CAT PCV EVAP		EGR PCV EVAP	EGR AIR PCV EVAP	PCV	PCV EVAP

[a] A = automatic transmission; M = manual transmission

used in all manual transmission equipped 1975 vehicles and in the 1976 California vehicles. Conversely, the 1975 engines with automatic transmission and all 1976 Federal engines are equipped with a modified camshaft, providing lower valve overlap. As discussed in Section 4.3.6, the reduction in valve overlap in these engines is compensated for by the use of higher EGR rates.

4.3.4.3. Air Intake System

All 250-CID engines incorporate a heated intake air system, consisting of an exhaust manifold heater and a temperature-controlled intake valve. The design and operational characteristics of the systems used since 1974 are identical to the corresponding model year systems described in Section 4.3.2.3 for the 2.3-liter engine. The system employed in 1969 is similar to the 1974 configuration.

4.3.4.4 Carburetor

4.3.4.4.1 Design Features

The Carter RBS carburetor used in the 1969-1974 model year engines is of the single-venturi type. The unit is equipped with two internal vapor vents which are designed to improve the idle and hot start characteristics of the engine by accelerating the fuel vapor dissipation process. A diaphragm-controlled stepup-type metering rod controls the fuel supply, and a spring-actuated accelerator pump provides the additional fuel needed for acceleration. The carburetor is equipped with a vacuum piston-type automatic choke, and a dashpot is used to control the rate of throttle return to idle. A throttle solenoid positioner is included in the 1974 configuration to prevent dieseling of the engine by closing the throttle plates farther when the ignition switch is turned off (Ref. 4-49). As indicated in Tables 4-24 and 4-25, the 1974 California engine is equipped with an electric assist choke, which is functionally identical to the unit described in Section 4.3.2.3 for the 2.3-liter engine. In 1970, the engine was equipped with the Ford IMCO (improved combustion) emission control system, consisting of special carburetor and distributor calibrations combined with reduced production tolerances. Subsequently, the carburetor bore and venturi diameters were reduced to improve the fuel atomization and vaporization processes by increasing the air velocity through the unit.

TABLE 4-24. EMISSION CONTROL SYSTEMS AND DEVICES: FORD 250-CID ENGINE WITH AUTOMATIC TRANSMISSION

Engine/Vehicle System	Model Year And Certification Standard[a]														
	1976 49-States		1976 California				1975 49-States			1975 California		1974 49-States			1974 California
Vehicle Model	Maverick	Monarch	Maverick	Monarch	Monarch	Maverick	Maverick	Comet	Maverick	Maverick	Comet	Maverick	Torino	Torino	Maverick
Certification Calibration	6-9G-R23	6-9G-R23	5-9N-R7S	6-9N-R20	5-9N-R9	6-9N-R20	5-9A-R6	5-9G-R2	5-9G-R2	5-9N-R7	5-9N-R7	4-9-R3	4-9C-R0	4-9C-R0	4-9T-R20
Vehicle Inertia Weight, lb	3500	4000	3500	4000	4000	3500	3500	4000	3500	3500	4000	3500	4000	4000	3500
Rear Axle Ratio	2.79	3.07	3.00	3.07	2.75	2.79	3.00	3.00	3.00	3.00	3.00	2.79	3.00	3.25	3.00
Emission Control Systems															
Air Injection	x	x	x	x	x	x	x	x	x	x	x				x
EGR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Oxidation Catalyst	x	x	x	x	x	x		x	x	x	x				
Crankcase Ventilation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Evaporative Control	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Emission Control Devices															
Hot Air-Heated Choke	x	x	x	x	x	x	x	x	x	x	x				
Electric Assist Choke	x	x	x	x	x	x	x	x	x	x	x				x
Fuel Deceleration Valve							x								
Air Cleaner Bimetal Sensor	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Duct and Valve	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Cold Weather Modulator	x	x	x	x	x	x	x	x	x	x	x				
EGR Valve[b]	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Tap stem	Poppet	Poppet	Poppet	Tap stem
EGR Venturi Vacuum Amplifier			Biased	Biased	Biased	Biased	Unbiased	Unbiased	Unbiased	Biased	Biased				Biased
EGR Vacuum Control Valve			x	x	x	x	x	x	x	x	x	x	x	x	x
EGR Delay Valve												x	x	x	x
Distributor Vacuum Control Valve			x	x	x	x	x	x	x	x	x	x	x	x	x
Spark Delay Valve			x	x	x	x	x	x	x	x	x	x	x	x	x
Thermactor Air Pump	x	x	x	x	x	x	x	x	x	x	x				x
Thermactor Air Bypass Valve	x	x	x	x	x	x	x	x	x	x	x				x
Thermactor Vacuum Differential Valve								x	x	x	x				
Thermactor Differential Valve Delay Valve										x	x				
Thermactor Retard Delay Valve	x	x													
Cold Lockout Air Cleaner TAV Switch[c]			x	x	x	x		x	x	x	x				
Floorpan Mounted Thermal Switch			x	x	x	x									
CTAV Temperature Sensor[d]							x					x	x	x	x
EGR Wide Open Throttle Cutoff															x
Air Cleaner Vacuum Control	x	x													

[a] X indicates system is used in model year shown, [b] Tap stem = tapered stem, [c] Temperature activated valve, [d] Coolant temperature activated valve

TABLE 4-25. EMISSION CONTROL SYSTEMS AND DEVICES: FORD 250-CID ENGINE WITH MANUAL TRANSMISSION

Engine/Vehicle System	Model Year And Certification Standard[a]											
	1976 49-States		1976 California		1975 49-States		1975 California			1974 49-States & California		
Vehicle Model	Comet	Granada	Comet	Granada	Maverick	Comet	Maverick	Maverick	Comet	Comet	Maverick	Comet
Certification Calibration	6-8G-R22	6-8G-R22	5-8N-R35	5-8N-R35	5-8A-R2	5-8G-R3	5-8G-R3	5-8N-R3	5-8N-R3	4-8C-R3	4-9U-R10	4-9U-R10
Vehicle Inertia Weight, lb	3500	4000	3500	4000	3500	3500	4000	4000	3500	3500	3500	3500
Rear Axle Ratio	3.00	2.75	3.00	3.07	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Emission Control Systems												
Air Injection	x	x	x	x	x	x	x	x	x		x	x
EGR	x	x	x	x	x	x	x	x	x	x	x	x
Oxidation Catalyst	x	x	x	x		x	x	x	x			
Crankcase Ventilation	x	x	x	x	x	x	x	x	x	x	x	x
Evaporative Control	x	x	x	x	x	x	x	x	x	x	x	x
Emission Control Devices												
Hot-Air Heated Choke	x	x	x	x	x	x	x	x	x			
Electric Assist Choke	x	x	x	x	x	x	x	x	x		x	x
Fuel Deceleration Valve			x	x	x	x	x	x	x			
Air Cleaner Bimetal Sensor	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Duct and Valve	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Cold Weather Modulator	x	x	x	x	x	x	x	x	x			
EGR Valve[b]	Tap stem	Tap stem	Poppet	Poppet	Poppet	Poppet	Poppet	Poppet	Poppet	Poppet	Poppet	Poppet
EGR Venturi Vacuum Amplifier			Unbiased	Unbiased				Unbiased	Unbiased			
EGR Vacuum Control Valve			x	x				x	x	x	x	x
EGR Delay Valve											x	x
Distributor Vacuum Control Valve			x	x	x	x	x	x	x	x	x	x
Spark Delay Valve			x	x		x	x	x	x	x	x	x
Thermactor Air Pump	x	x	x	x	x	x	x	x	x		x	x
Thermactor Air Bypass Valve	x	x	x	x	x	x	x	x	x		x	x
Thermactor Vacuum Differential Valve						x	x	x	x			
Thermactor Differential Valve Delay Valve			x	x				x	x			
Thermactor Idle Dump Valve	x	x										
Thermactor Retard Delay Valve	x	x										
Cold Lockout Air Cleaner TAV Switch[c]			x	x		x	x	x	x			
Floorpan Mounted Thermal Switch			x	x								
CTAV Temperature Sensor[d]										x		
Air Cleaner Vacuum Control	x	x										

[a] X indicates system is used in model year shown, [b] Tap stem - tapered stem, [c] Temperature-activated valve, [d] Coolant temperature-activated valve

All 1975 and 1976 model 250-CID engines incorporate a single-venturi Carter YFA carburetor, which is equipped with an accelerator pump, a hot air heated electric assist choke, a fuel bowl vent for the control of evaporative emissions after engine shutdown, and a solenoid throttle positioner designed to prevent stalling of the engine and dieseling. The hot air and electric assist features are described in Section 4. 3. 2. 3.

Several of the engines listed in Tables 4-24 and 4-25 incorporate an FDV. As discussed in Section 4. 3. 2. 4, the FDV supplies additional mixture into the intake manifold for added HC control during deceleration.

4. 3. 4. 4. 2 Carburetor Calibration

The air/fuel ratio of the certification vehicles is listed in Tables 4-26 and 4-27 for automatic and manual transmissions, respectively, showing the air/fuel ratio at idle, off idle, part-throttle, and WOT. In general, the air/fuel ratio shows a declining trend between 1974 and 1976, which is consistent with the previously discussed 2. 3-liter and 2. 8-liter engines, except for the 1974 to 1975 time period when the air/fuel ratio of the latter engines was slightly increased. While the 250-CID engine operates richer than the 2. 3- and 2. 8-liter engines, indicating higher untreated HC and CO emission levels, Ford has apparently optimized the carburetor in conjunction with the spark timing and EGR systems to meet the emission standards, consistent with acceptable vehicle driveability and fuel economy.

The 1969 carburetor provides a rich mixture which has been leaned out in subsequent years to meet the HC and CO emission regulations in effect at the time.

4. 3. 4. 5 Ignition System

4. 3. 4. 5. 1 Design Features

Prior to 1974, all 250-CID engines were equipped with a conventional breaker-point ignition system. In 1974, Ford introduced its breakerless ignition system in California to prevent an increase in HC emissions during mileage accumulation caused by breaker-point deterioration.

The 1976 model 49-states vehicles listed in Tables 4-24 through 4-27 incorporate a conventional single diaphragm vacuum advance unit, whereas a dual diaphragm unit is used in all other vehicles. While the single

TABLE 4-26. CERTIFICATION CALIBRATION DATA: FORD 250-CID ENGINE WITH AUTOMATIC TRANSMISSION

ENGINE / VEHICLE PARAMETER	Model Year and Certification Standard																
	1976 49 States		1976 California				1975 49 States			1975 California		1975 49 States			1974 Calif	1970	1969
Vehicle Model	Ma[a]	Mo[b]	Ma[a]	Mo[b]	Mo[b]	Ma[a]	Ma[a]	Cx[c]	Ma[a]	Ma[a]	C[d]	Ma[a]	T[e]	T[e]	Ma[a]	FM[f]	FM[f]
Certification Calibration	6-9G -R23	6-9G -R23	5-9N -R75	6-9N -R20	5-9N -R9	6-9N -R20	5-9A -R6	5-9G -R2	5-9G -R2	5-9N -R7	5-9N -R7	4-9 -R3	4-9C -R0	4-9C -R0	4-9T -R20	In-Use	In-Use
Vehicle Inertial Weight, lb	3500	4000	3500	4000	4000	3500	3500	4000	3500	3500	4000	3500	4000	4000	3500	3500	-
Rear Axle Ratio	2.79	3.07	3.00	3.07	2.75	2.79	3.00	3.00	3.00	3.00	3.00	2.79	3.00	3.25	3.00	-	-
Catalyst	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Carburetor Calibration, A / F																	
Idle	8.7	8.7	10.6	10.5	10.6	10.5	10.6	10.6	10.6	10.6	10.6	12.1	12.1	12.1	12.1	-	-
Off Idle	12.5	12.5	13.5	12.2	13.5	12.2	13.7	13.7	13.7	13.6	13.6	13.7	13.7	13.7	13.7	-	-
Part Throttle	13.8	13.8	14.3	13.6	14.3	13.6	14.7	14.7	14.7	14.3	14.3	15.6	15.6	15.6	15.6	-	-
WOT	13.0	13.0	12.8	13.3	12.8	13.3	12.8	12.8	12.8	12.8	12.8	13.5	13.5	13.5	13.5	-	-
Basic Timing, crankshaft deg BTC	12	12	6	8	10	8	6	6	6	6	6	6	6	6	6	6	6
Centrifugal Advance, crankshaft deg																	
1000 rpm	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	3	6.5
1500 rpm	5	5	5	5	5	5	5	5	5	5	5	9	9	9	9	14	17.5
2000 rpm	7	7	7.5	7.5	7.5	7.5	8	8	8	8	8	12.5	12.5	12.5	12.5	17	20
3000 rpm	11	11	12.5	11	12.5	11	12.5	12.5	12.5	12.5	12.5	15	15	15	15	22	25
4000 rpm	14.5	14.5	18	15	18	15	18	18	18	18	18	17	17	17	18	27.5	29.5
5000 rpm	18	18	22.5	18	22.5	18	23	23	23	23	23	20	20	20	21	-	29.5
Vacuum Advance, crankshaft deg																	
4 in. Hg	3	3	1	3	1	3	1	1	1	1	1	0	0	0	0	0	0
5 in. Hg	6	6	1.5	7	1.5	7	1.5	1.5	1.5	1.5	1.5	4	4	4	5	1	1
6 in. Hg	10	10	2.5	10	2.5	10	2.5	2.5	2.5	2.5	2.5	8	8	8	8	1.5	3.5
8 in. Hg	16	16	7	16	7	16	7	7	7	7	7	15	15	15	14	5.5	9.5
10 in. Hg	19	19	8	19	8	19	8	8	8	8	8	16	15	16	16	11.5	13
12 in. Hg	20	20	8	20	8	20	8	8	8	8	8	16	16	16	16	15.5	15
15 in. Hg	20	20	8	20	8	20	8	8	8	8	8	16	16	16	16	15.5	15.5
EGR Valve Calibration																	
Signal Pressure To Open, in. Hg	2.5	2.5	2.5	2.5	2.5	2.5	3.0	3.0	3.0	2.5	2.5	2.9	2.9	2.9	2.5	-	-
Flow at 12 in. Hg, cfm	22.4	22.4	22.4	22.4	22.4	22.4	11.2	11.2	11.2	22.4	22.4	10.9	10.9	20.9	22.4	-	-
Fuel Economy, mpg																	
City	17	16	13	15	13	16	14	14	15	15	14	15.6[g]	-	14.0[g]	14.5[g]	17.0	-
Highway	21	19	17	20	19	22	18	19	19	21	20	-	-	-	-		-
Exhaust Emissions, g/m																	
HC	1.3	1.3	0.6	0.9	0.8	0.8	1.2	0.4	0.3	0.4	0.6	2.2[g]	2.0[g]	2.5[g]	2.0[g]	4.0	-
CO	4	7	3.8	3.5	5.5	2.9	1.3	4	2	1	4	27[g]	31[g]	37[g]	21[g]	42[g]	-
NO_x	2.0	2.2	1.1	1.7	1.5	1.5	2.3	2.8	2.6	1.4	1.6	2.2[g]	3.0[g]	2.7[g]	1.6[g]	5.8	-

[a] Maverick

[b] Monarch

[c] Comet X

[d] Comet

[e] Torino

[f] Fairlane; Mustang

[g] 1972 FTP

TABLE 4-27. CERTIFICATION CALIBRATION DATA: FORD 250-CID ENGINE WITH MANUAL TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard													
	1976 49 States		1976 California		1975 49 States			1975 California		1974 49 States	1974 California		1970	1969
Vehicle Model	C[a]	G[b]	C[a]	G[b]	Ma[c]	C[a]	Ma[c]	Ma[c]	C[a]	C[a]	Ma[c]	C[a]	FM[d]	FM[d]
Certification Calibration	6-8G-R23	6-8G-R22	5-8N-R35	5-8N-R35	5-8A-R2	5-8G-R3	5-8G-R3	5-8N-R3	5-8N-R3	4-8C-R3	4-9U-R10	4-9U-R10	In-use	In-use
Vehicle Inertia Weight	3500	4000	3500	4000	3500	3500	4000	4000	3500	3500	3500	3500	-	-
Rear Axle Ratio	3.00	2.75	3.00	3.07	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	-	-
Catalyst	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	No	No	No
Carburetor Calibration, A/F														
Idle	8.1	8.1	10.2	10.2	12.6	12.6	12.6	10.2	10.2	12.7	12.1	12.1	-	-
Off Idle	12.4	12.4	13	13	14.3	14.3	14.3	13	13	14.2	13.7	13.7	-	-
Part Throttle	13.7	13.7	14.8	14.8	15.4	15.4	15.4	14.8	14.8	15.6	15.6	15.6	-	-
WOT	13.1	13.1	13.1	13.1	12.8	12.8	12.8	12.8	12.8	13.7	13.6	13.6	-	-
Basic Timing, crankshaft deg BTC	8	8	6	6	6	6	6	6	6	6	6	6	-	-
Centrifugal Advance, crankshaft deg														
1000 rpm	0	0	0	0	0	0	0	0	0	2	1	1	3	2
1500 rpm	3	3	5	5	4	3	3	5	5	9.5	9.5	9.5	14	11
2000 rpm	11.5	11.5	7.5	7.5	10.5	10.5	10.5	7.5	7.5	11	11	11	17	13
3000 rpm	21	21	12.5	12.5	15	15	15	12.5	12.5	15	14	14	22	16.5
4000 rpm	24	24	18	18	17	17	17	18	18	17	16.5	16.5	27.5	20
5000 rpm	27	27	22.5	22.5	19	19	19	23	23	19.5	19	19	-	-
Vacuum Advance, crankshaft deg														
4 in. Hg	3	3	1	1	4	4	4	1	1	1	0	0	0	0
5 in. Hg	6	6	1.5	1.5	7	7	7	1.5	1.5	4	1	1	1	0
6 in. Hg	10	10	2.5	2.5	8	8	8	2.5	2.5	9	4	4	1.5	1
8 in. Hg	16	16	7	7	8	8	8	7	7	15	13	13	5.5	3
10 in. Hg	19	19	8	8	8	8	8	8	8	16	16	16	11.5	9.5
12 in. Hg	20	20	8	8	8	8	8	8	8	16	16	16	15.5	14
15 in. Hg	20	20	8	8	8	8	8	8	8	16	16	16	15.5	14.5
EGR Valve Calibration														
Signal Pressure To Open, in. Hg	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	-	-
Flow at 12-in. Hg, cfm	6.1	6.1	10.9	10.9	6.1	6.1	6.1	10.9	10.9	2.9	15.1	15.1	-	-
Fuel Economy, mpg														
City	18	18	16	14	14	18	18	15	16	17.2[e]	16.7[e]	15.1[e]	-	-
Highway	23	24	23	19	22	26	23	20	23	-	-	-	-	-
Exhaust Emissions, g/m														
HC	1.3	1.2	0.2	0.7	1.1	0.3	0.6	0.4	0.2	2.6[e]	3.1[e]	3.4[e]	-	-
CO	9	8	1.9	4.2	7	1	8	4	2	24[e]	17[e]	35[e]	-	-
NO_x	2.4	2.1	1.8	1.7	2.7	3.0	3.1	1.9	1.8	2.7[e]	1.8[e]	1.7[e]	-	-

[a] Comet

[b] Granada

[c] Maverick

[d] Fairlane; Mustang

[e] 1972 FTP

diaphragm configuration has only an advance function, the dual diaphragm unit is designed to provide 12 deg spark retard during vehicle deceleration and idle for the 1975 model 49-states vehicles and 6 deg retard for all other vehicles.

4.3.4.5.2 Spark Timing Control Devices

As shown in Tables 4-24 and 4-25, most 250-CID engines are equipped with a temperature-controlled PVS valve which increases spark advance in the case of engine overheating. In addition, a SDV is used which aids in the control of HC and NO_x by delaying vacuum advance during acceleration, at the expense of a slight loss in fuel economy. Both valves are similar to the units previously described for the 2.3- and 2.8-liter engines.

4.3.4.5.3 Spark Advance Schedules

The centrifugal and vacuum advance settings at discrete engine speed and port vacuum settings are listed in Tables 4-26 and 4-27. The data for model years 1974-1976 were extracted from Ford documents (Ref. 4-43 through 4-50), whereas the 1969 and 1970 data were provided by the Ethyl Corporation (Refs. 4-57 and 4-58). For examination of spark timing and its impact on fuel economy, Figures 4-44 and 4-45 present the average centrifugal and vacuum advance of the certification vehicles with automatic transmission (Table 4-26) as a function of model year, vehicle speed, and port vacuum level. The dashed portion of the various curves encompasses the time period not examined in this study. As indicated in Figure 4-44, the centrifugal advance, which includes the basic spark timing, shows a declining trend for the 1969-1975 time period, reflecting the increasingly stringent emission regulations. This is followed by a partial restoration of the advance in 1976, particularly in the low-speed regime. Similar trends are observed for the California vehicles with automatic transmission and all vehicles with manual transmission, except for the increase in advance implemented in 1970. In 1976, the vacuum advance of two California vehicles with automatic transmission was sharply increased (Table 4-26) as a means of achieving better fuel economy.

The vacuum advance schedules shown in Figure 4-45 indicate some increase in vacuum advance between 1969 and 1974, particularly in the low vacuum (high load) regime, followed by a decline in 1975 and a sharp

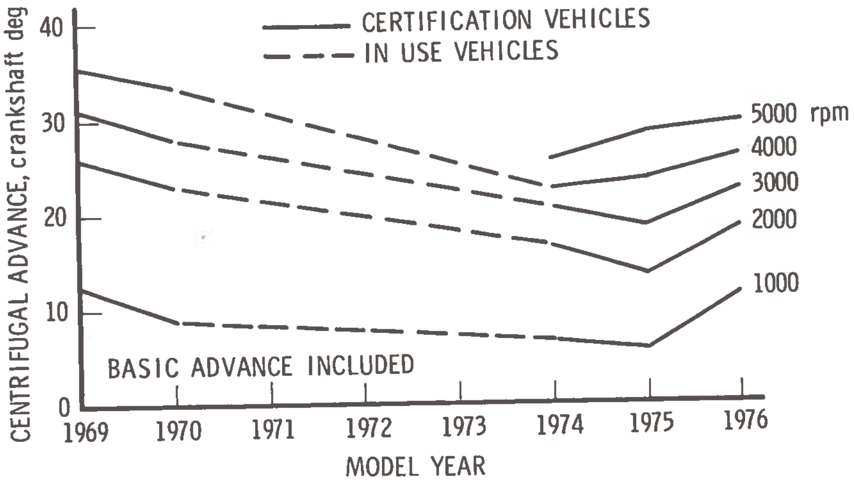


FIGURE 4-44. CENTRIFUGAL SPARK ADVANCE SCHEDULE: FORD 250-CID ENGINE WITH AUTOMATIC TRANSMISSION; 49-STATES CALIBRATION

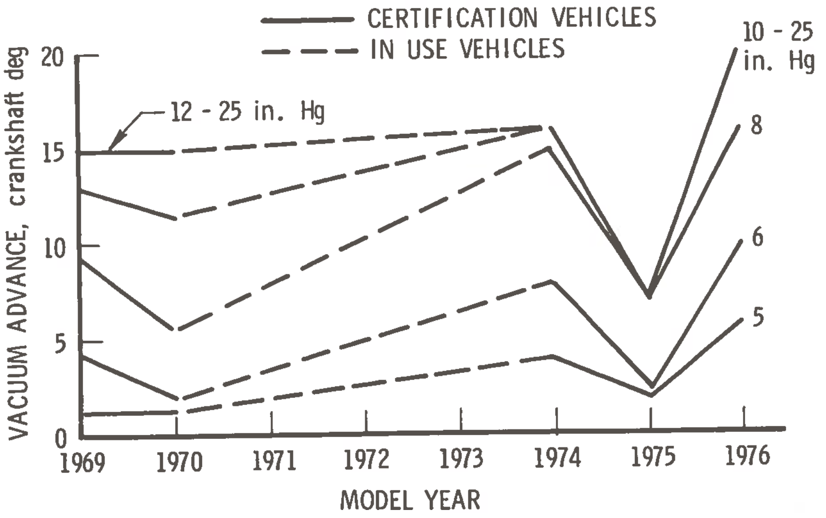


FIGURE 4-45. VACUUM SPARK ADVANCE SCHEDULE: FORD 250-CID ENGINE WITH AUTOMATIC TRANSMISSION; 49-STATES CALIBRATION

increase in 1976. Part of the observed reduction in 1975 might be related to small variations in the location and sensitivity of the carburetor vacuum port. In any event, the higher vacuum advance shown in 1976 has been implemented by Ford to improve vehicle fuel economy. Similar trends are observed for the California vehicles with automatic transmission and the 49-states vehicles with manual transmission. Conversely, the California vehicles with manual transmission use the same vacuum advance calibration in 1975 and 1976.

4.3.4.6 Exhaust Gas Recirculation

4.3.4.6.1 Design Features

All 1974-1976 model year 250-CID engines are equipped with an EGR system for NO_x control. As indicated in Tables 4-24 and 4-25, most vehicles with automatic transmission incorporate a venturi vacuum-controlled EGR system with vacuum amplifier, tapered stem EGR flow control valve, and EGR vacuum-control valve. Conversely, for the vehicles with manual transmission, Ford favors a port vacuum-controlled system with poppet valve but without amplifier. Most of the 1974 model engines incorporate an EGR delay valve which delays the opening of the EGR flow valve during sudden changes in the vacuum signal to prevent engine stumble caused by a sudden increase in the EGR flow rate.

The EGR system and components used in the 250-CID engine are functionally identical to those previously described for the 2.3- and 2.8-liter engines (Sections 4.3.2.6 and 4.3.3.6), except that the exhaust gas is provided by an external tube from the exhaust manifold rather than directly from the crossover.

One of the engines listed in Table 4-14 incorporates an EGR WOT cutoff valve which dumps the EGR vacuum whenever the venturi vacuum is equal to or greater than the intake manifold vacuum. This allows the EGR valve to close when maximum engine power is required.

4.3.4.6.2 EGR Valve Calibration

Tables 4-26 and 4-27 list the EGR valve calibration data, which show the signal pressure required to open the valve and the flow rate through the valve corresponding to a signal vacuum of 12-in. Hg. While there is insufficient information to determine the EGR flow over the range of engine operating conditions, the data permit qualitative comparisons to be made regarding the level of EGR used in the various vehicles and model years.

Because of the more stringent NO_x standards in California, the vehicles certified for use in California have higher EGR flows than the 49-states vehicles. While the EGR rates used in the 2.3- and 2.8-liter engines have been changed frequently by Ford, between 1974 and 1976, the 250-CID engine shows only minor EGR flow variations for the 49-states and California calibrations, except for the 1974 California vehicles with manual transmission, which use rather high EGR flows. In subsequent model years, Ford replaced the simple ported vacuum EGR system with a more sophisticated venturi vacuum system with amplifier, which permits a reduction in EGR, as indicated in Table 4-26 and 4-27.

The EGR flow rates used in the manual transmission-equipped vehicles are generally lower than for the vehicles with automatic transmission. According to Ford, this is due to the lower efficiency of the automatic transmission in the operating range corresponding to the Federal Driving Cycle and the related increase in engine load and NO_x formation rates.

4.3.4.7 Thermactor Exhaust Emission Control System

With the exception of the 1974 model 49-states vehicles, all 1974-1976 model 250-CID engines are equipped with the thermactor system for HC and CO control. The system consists of an air pump, an air bypass valve, a check valve, and a number of optional components incorporated in some of the vehicles listed in Tables 4-24 through 4-27. These include a VDV, an idle dump valve, a retard delay valve, a cold lockout TAV switch, and a floorpan-mounted thermal switch.

Descriptions of the basic thermactor system and its components are included in Section 4.3.2.7 and 4.3.3.7. The 1975 California vehicles incorporate a thermactor differential valve delay valve (DVDV), which aids in the control of HC and CO by delaying thermactor bypass during periods of low manifold vacuum. The valve is installed in series with the VDV and consists of a sintered metal disk with a high flow resistance.

The air pump is identical to the pump used in the 2.3- and 2.8-liter engines, except that the pulley drive ratio has been increased to 1.37.

Again, the power requirement of the pump is small and has little impact on vehicle emissions and fuel economy.

4.3.4.8 Catalytic Converter

Except for two 1975 model 49-states vehicles, all 1975 and 1976 certification vehicles listed in Tables 4-24 through 4-27 are equipped with one monolithic precious metal catalyst of the type described in Section 4.2.2.8. The substrate is oval shaped (3.66 x 6.66 inches), with a length of 6 inches and a total precious metal loading of 0.11 troy oz for the California vehicles and 0.10 troy oz for the 49-states vehicles.

4.3.4.9 Fuel Economy and Emissions

The fuel economy and emission certification data for the 250-CID engine/vehicle configurations are listed in Tables 4-26 and 4-27 for automatic and manual transmissions, respectively. (Refs. 4-15, 4-17, and 4-19). For interpretation of the observed fuel economy variations, as affected by the increasingly stringent emission regulations implemented since 1966 and the related modifications in the carburetor, distributor, and EGR system calibrations, the city fuel economy of the certification vehicles has been normalized, using a common inertia weight of 3500 pounds and a common rear axle ratio of 3.00. The method of normalizing the test data is described in Section 3.

The normalized city fuel economy data, averaged for each model year and calibration level (49-states and California), are presented in Figures 4-46 and 4-47 for automatic and manual transmissions, respectively. The curves presented include all certification data listed in Tables 4-25 and 4-26, except for the 1976 model California vehicles with automatic transmission. In this case, because of their superior fuel economy which is directly attributed to the higher vacuum spark advance used in these vehicles, only the 4000 pound Monarch with 3.07 axle ratio and the 3500 pound Maverick with the 2.79 axle ratio have been considered. Also included in these figures is the normalized average fuel economy of the 1973 certification vehicles, (Ref. 4-21) and a number of 1970-1972 model year in-use vehicles (Refs. 4-37 through 4-40). Following the previously described procedure, the fuel economy of the 1973 and 1974 model year vehicles was increased by 5 percent to account for the different test procedures used in these particular vehicle tests. Unlike the certification

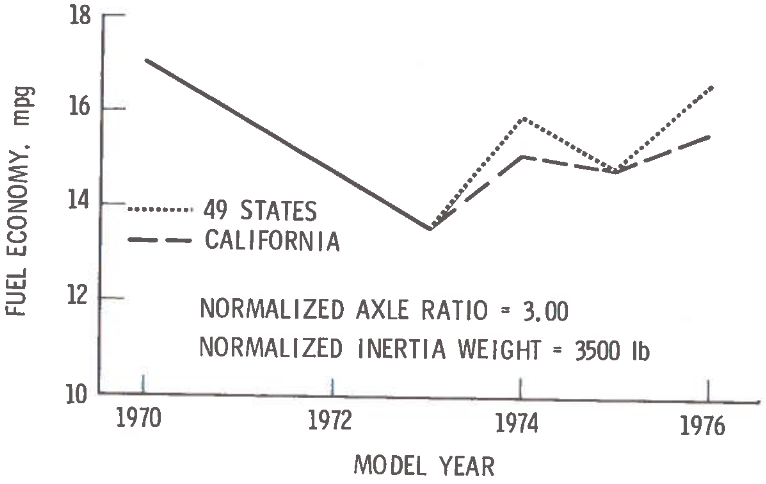


FIGURE 4-46. NORMALIZED AVERAGE CITY FUEL ECONOMY: FORD 250-CID ENGINE WITH AUTOMATIC TRANSMISSION

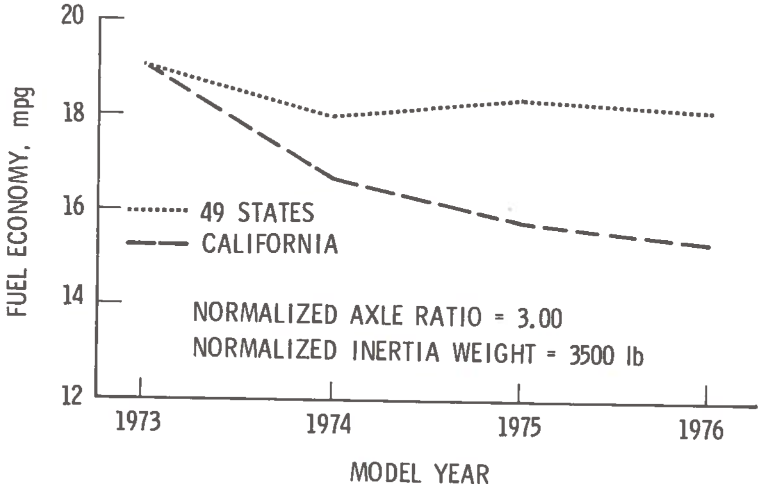


FIGURE 4-47. NORMALIZED AVERAGE CITY FUEL ECONOMY: FORD 250-CID ENGINE WITH MANUAL TRANSMISSION

vehicles which have been well-tuned, the in-use vehicles were tested in an "as is" condition, and this may have introduced a downside bias in the measured fuel economy of these vehicles.

The average HC, CO, and NO_x emissions of the 49-states and California certification and in-use vehicles are presented in Figures 4-48 through 4-51, for automatic and manual transmissions, respectively. The emissions of the 1973 and 1974 model year vehicles, which were determined in accordance with the 1972 FTP, have been converted to 1975 FTP levels, using the conversion factors (0.89 for HC, 0.72 for CO, and 1.03 for NO_x) from Ref. 4-42.

As shown in Figure 4-46, the fuel economy of the vehicles with automatic transmission decreases between 1970 and 1973. This decline is attributed to the reduction in centrifugal spark advance (Figure 4-44) and the use of EGR in 1973. As a result of these calibration changes, the emissions have declined accordingly, as illustrated in Figure 4-48. In 1974, the fuel economy of the 49-states vehicles show an increase of about 15 percent, followed by a slight reduction in 1975, and a moderate increase in 1976. The fuel economy decline in the 1975 model 49-states vehicles is caused primarily by the reduction in centrifugal and vacuum spark advance (Figures 4-44 and 4-45), particularly in the low-speed and high port vacuum regimes, combined with a slight increase in EGR and a reduction of the part-load air/fuel ratio in 1975 relative to 1974. Because of the low HC levels of the 1975 certification vehicles (Figure 4-48), Ford has recalibrated the engine, in 1976, by substantially increasing the centrifugal and vacuum advance. To counteract the higher NO_x formation rates associated with spark advance, the EGR rate has been increased, which has lowered the NO_x emission relative to 1975 and provides an additional margin of safety. To compensate for the lower flame speed with EGR, the mixture has been enriched at off idle and part throttle, as shown in Table 4-25.

The California vehicles with automatic transmission follow similar trends, showing a decline in fuel economy in 1975, which is attributed to the lower spark advance used in conjunction with mixture enrichment in the part-load regime. Again, the HC emissions in 1975 are considerably below the standard, permitting recalibration of the two selected 1976 vehicles. While a small increase in NO_x occurs in 1976 as a result of higher spark

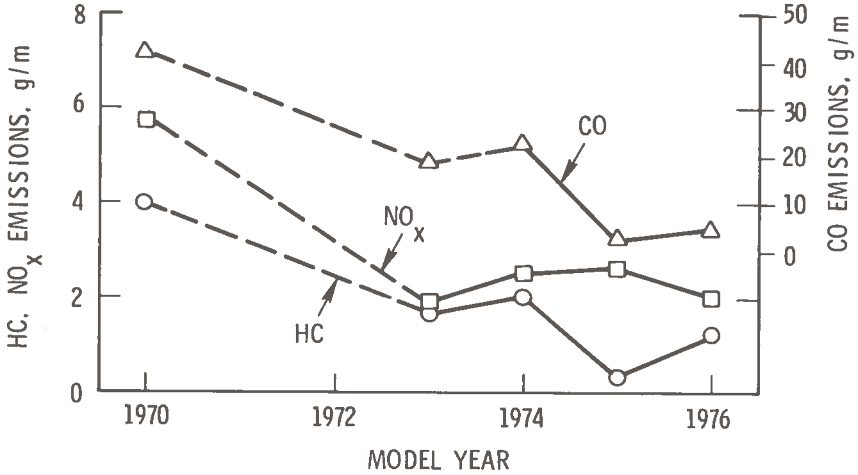


FIGURE 4-48. AVERAGE EXHAUST EMISSIONS: FORD 250-CID ENGINE WITH AUTOMATIC TRANSMISSION; 49-STATES CALIBRATION; 1975 FTP

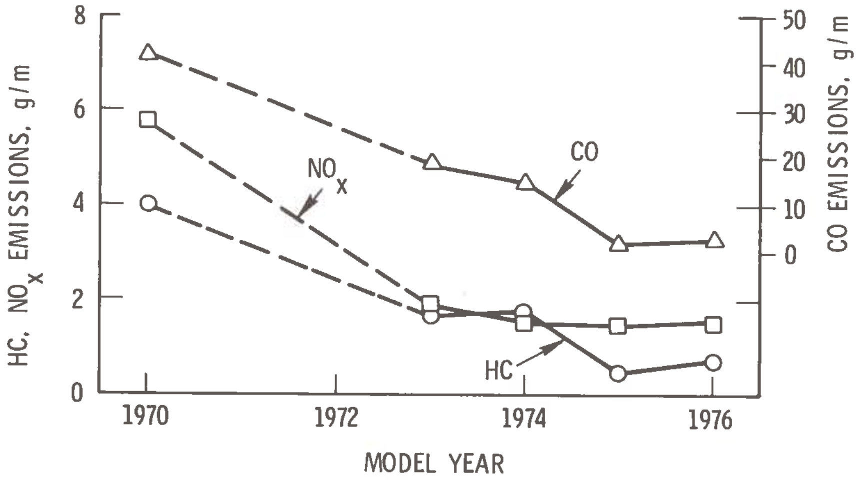


FIGURE 4-49. AVERAGE EXHAUST EMISSIONS: FORD 250-CID ENGINE WITH AUTOMATIC TRANSMISSION; CALIFORNIA CALIBRATION; 1975 FTP

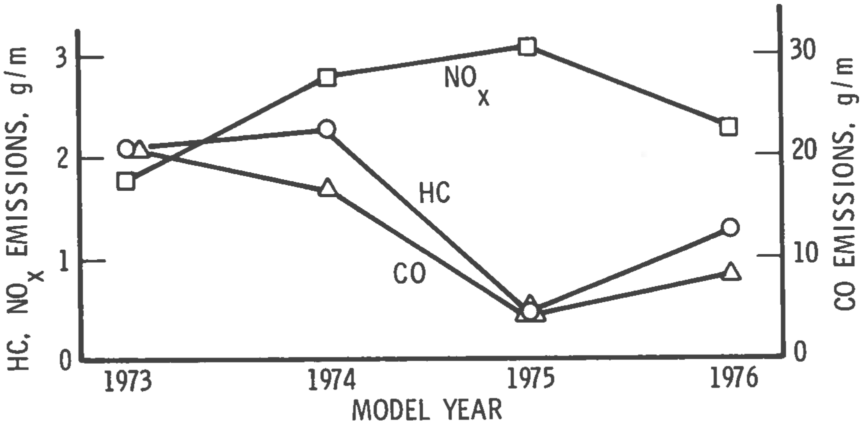


FIGURE 4-50. AVERAGE EXHAUST EMISSIONS: FORD 250-CID ENGINE WITH MANUAL TRANSMISSION; 49-STATES CALIBRATION; 1975 FTP

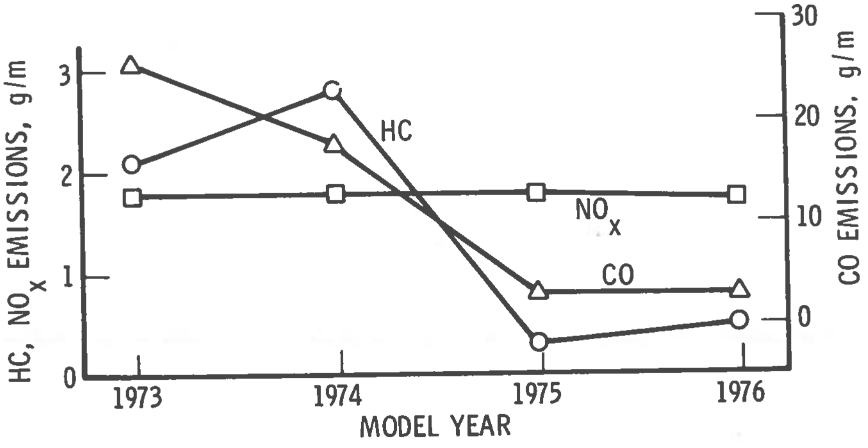


FIGURE 4-51. AVERAGE EXHAUST EMISSIONS: FORD 250-CID ENGINE WITH MANUAL TRANSMISSION; CALIFORNIA CALIBRATION; 1975 FTP

advance, the increase has been diminished by simultaneously reducing the air/fuel ratio at off idle and part throttle.

The fuel economy of the 49-states vehicles with manual transmission declined slightly in 1974 relative to 1973 and has remained nearly constant between 1974 and 1976. Although the air/fuel ratio was reduced in 1976, it is surprising that no fuel economy improvement was realized in 1976, considering the large increase in spark advance in 1976 relative to 1975 (Table 4-27). It is conceivable, however, that the small variations in the location of the carburetor spark port implemented by Ford over the years could have altered the relationship between engine operating condition and vacuum port signal.

The calibration data for the 1975 California vehicles show a substantial decline in both centrifugal and vacuum spark advance (Table 4-27), permitting a reduction of the EGR flow with no penalty in NO_x. Since the same calibrations have been employed in the 1976 vehicles, it is not surprising that the fuel economy of these vehicles is nearly equal to the 1975 vehicles. The highway fuel economy data follow similar trends.

4.3.5 Ford 351W Engine

4.3.5.1 Engine Design Features

The 351W engine is a V-8 overhead valve design with a total piston displacement of 351 cu in.. Introduced in 1969, the engine incorporates a closed-loop CCV system of the type described in Section 3. In 1970, an evaporative emission control system was added in the California engines, and this system has been used nationwide since 1971. The functional characteristics of the evaporative emission control system are similar to the system previously described in Section 3. To meet the increasingly stringent California and 49-states exhaust emission control regulations, Ford has altered the original distributor and carburetor calibrations over the years and has incorporated a number of engine modifications and emission control devices which are described in the following sections. It should be noted that all 1973 and later model year vehicles incorporating this engine are equipped with automatic transmission. The engine was not offered in California in 1974.

4.3.5.2 Engine Modifications

The basic design of the engine has remained unchanged since its introduction in 1969. However, as indicated in Table 4-28, the compression ratio has been reduced from 9.5 in 1969 to 8.1 in 1976 to permit the use of 91 octane gasoline (Refs. 4-39 and 4-43 through 4-50). While this modification is beneficial in terms of HC and NO_x emissions, it has resulted in a loss in fuel economy of the order of 4 percent (Refs. 4-40 and 4-41).

In an effort to reduce the formation of NO_x during the combustion process, Ford has increased the residual exhaust gas fraction remaining in the cylinder in 1974 by increasing the valve overlap relative to the 1969 design. Additional valve timing modifications have been implemented, in 1975 and 1976, to improve the fuel consumption characteristics of the engine at the expense of slightly higher emissions.

4.3.5.3 Air Intake System

Like the three other Ford engines considered in this study, the 351W engine incorporates a heated intake air system which is composed of an exhaust manifold heater and a temperature-controlled intake valve as described in Sections 4.3.2.3 and 4.3.3.3. The principal objective of this system is the achievement of lower HC and CO emissions by means of better fuel vaporization and mixture preparation, particularly during engine warmup. As shown in Table 4-29, a cold weather modulator is used in 1975 and 1976 to prevent sudden cooling of the intake air during engine warmup and at low ambient temperatures.

For control of cold start HC and CO emissions, all 1975 model 351W engines and the 1976 California engines incorporate an intake manifold heater of the type described in Section 4.3.3.3.

4.3.5.4 Carburetor

4.3.5.4.1 Design Features

All 1970-1974 model 351W engines are equipped with a Ford model 2100 D-2V carburetor, which is composed of two venturis, an accelerator pump assembly, a power valve assembly, and an automatic choke system.

TABLE 4-28. ENGINE SPECIFICATIONS: FORD 351W ENGINE

Engine Parameter	Model Year							
	1976[a]		1975[a]		1974[a, b]		1969	
	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	8		8		8		8	
Bore, in.	4.00		4.00		4.00		4.00	
Stroke, in.	3.50		3.50		3.50		3.50	
Displacement, cu in.	351		351		351		351	
Surface/Volume, 1/in.	6.4		6.4		6.4		-	
Compression Ratio	8.1		8.1		8.2		9.5	
Cylinder Head Type	OHV		OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	150 at 3600		148 at 3800		162 at 4000		250[c] at 4600	
Torque, ft-lb, at Engine Speed, rpm	264 at 2200		243 at 2200		275 at 2200		355[c] at 2600	
Exhaust System Type	Single		Single		Single		Single	
Combustion Chamber Configuration	Wedge		Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.78		1.78		1.84		1.84	
Intake Valve Lift, in.	0.415	0.419	0.415	0.419	0.419		0.418	
Exhaust Valve Diameter, in.	1.45		1.45		1.54		1.54	
Exhaust Valve Lift, in.	0.415	0.448	0.415	0.448	0.448		0.448	
Intake Valve Opens, deg BTC	23	15	23	15	15		11	
Intake Valve Closes, deg ABC	53	65	53	65	65		65	
Intake Valve Duration, deg	256	260	256	260	260		256	
Exhaust Valve Opens, deg BBC	58	68	58	68	68		68	
Exhaust Valve Closes, deg ATC	18	26	18	26	26		22	
Exhaust Valve Duration, deg	256	274	256	274	274		270	
Valve Overlap, deg in.	0.52	0.49	0.52	0.49	0.49		33 deg	
Distributor Type	Breakerless		Breakerless		Breaker point		Breaker point	
Basic Ignition Advance, deg BTC	8-11	6-10	4-6	6	6-10		10	
Idle Speed, rpm[d]	650		650		600		600 (A) 700 (M)	
Fast Idle Speed, rpm[d]	2000		1400				1600 (A) 1300 (M)	
Fuel System Type	2-V downdraft Ford 2150		2-V downdraft Ford 2150		2-V downdraft Ford 2100 D		2-V downdraft Ford 2100	
Fuel Metering Method	Fixed orifice		Fixed orifice		Fixed orifice		Fixed orifice	
Enrichment Method	Vacuum valve, velocity feed		Vacuum valve, velocity feed		Vacuum Valve		-	
Choke Type	Automatic electric assist		Automatic electric assist		Automatic electric assist		-	
Carburetor Venturi Diameter, in.	1.21		1.21		1.21		1.23	
Carburetor Maximum Air Flow, lb/min, at Vacuum, in. Hg	26.9 lb/min at 3 in. Hg		26.9 lb/min at 3 in. Hg		-		-	
Emission Control Systems	EGR AIR CAT PCV EVAP		EGR AIR CAT PCV EVAP		EGR EVAP PCV		PCV IMCO	

[a] Automatic transmission only in 1974-1976

[b] Not offered in California

[c] Gross rating

[d] A = automatic transmission; M = manual transmission

TABLE 4-29. EMISSION CONTROL SYSTEMS AND DEVICES: FORD 351W ENGINE WITH AUTOMATIC TRANSMISSION

Engine Vehicle System	Model Year And Certification Standard[a]														
	1976 49-States		1976 California		1975 49-States			1975 California		1974 49-States				1970	1969
Vehicle Model	Granada, Monarch	Granada	Monarch	Granada	Maverick	Maverick	Torino	Maverick	Maverick	Torino	Ford	Ford	Montego	Fairlane	Cougar
Certification Calibration	6-12H-R0	6-12H-R1	5-12N-R55	6-12N-R7	5-12A-R3	5-12A-R5	5-12G-R4	5-12N-R5	5-12N-R5	4-12-R0	4-12B-R0	4-12D-R0	4-12E-R0	-	-
Vehicle Inertia Weight, lb	4000	4000	4000	4000	4000	4000	4500	4000	4500	4500	5000	4500	5000	3500 - 4500	3000 - 4500
Rear Axle Ratio	2.75	2.75	3.07	2.75	3.00	3.07	3.07	3.07	3.07	2.75	2.75	3.25	3.25	-	-
Emission Control Systems															
IMCO[b]														x	x
Air Injection	x	x	x	x	x	x	x	x	x						
EGR	x	x	x	x	x	x	x	x	x	x	x	x	x		
Oxidation Catalyst	x	x	x	x			x	x	x						
Crankcase Ventilation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Evaporative Control	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Emission Control Devices															
Hot Air-Heated Choke	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Electric Assist Choke	x	x	x	x	x	x	x	x	x	x	x	x	x		
Air Cleaner Bimetal Sensor	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Duct and Valve	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Air Cleaner Cold Weather Modulator	x	x	x	x	x	x	x	x	x						
EGR Valve[c]	Tap stem	Tap stem	Tap stem Biased	Tap stem Biased	Poppet	Poppet	Tap stem	Tap stem Biased	Tap stem Biased	Modulating	Modulating	Modulating	Modulating		
Venturi Vacuum Amplifier															
EGR Vacuum Control Valve	x	x	x	x	x	x	x	x	x	x	x	x	x		
EGR Backpressure Transducer	x	x													
Thermactor Air Pump	x	x	x	x	x	x	x	x	x						
Thermactor Air Bypass Valve	x	x	x	x	x	x	x	x	x						
Thermactor Delay Valve	x	x													
Cold Lockout Air Cleaner TAV Switch[d]			x	x			x	x	x						
Floorpan Mounted Thermal Switch			x	x											
Distributor Vacuum Control Valve			x	x	x	x	x	x	x	x	x	x	x		
Spark Delay Valve										x	x	x	x		
Exhaust Heat Control Valve			x	x	x	x	x	x	x						
Exhaust Heat Control Vacuum Motor			x	x	x	x	x	x	x						

[a] X indicates system is used in model year shown, [b] Improved combustion emission control system, [c] Tap stem = tapered stem, [d] Temperature-activated valve

In addition, the 1974 carburetor employs a TSP which prevents dieseling of the engine after the ignition key has been turned off. Each carburetor bore contains a main venturi, a booster venturi, a main fuel discharge, an accelerator pump discharge, and an idle flow discharge. The hot air heated automatic choke is designed to assist in the control of HC and CO during engine warmup by reducing the choke action time. The 1969 engine is fitted with a Ford 2100-2V carburetor, which is a forerunner of the 2100 D configuration. HC and CO control is implemented in this engine by means of the IMCO (improved combustion) emission control system, which utilizes special carburetor and distributor calibration settings combined with lower production tolerances. With IMCO, the air/fuel mixture has been leaned out relative to the pre-emission control settings, and the spark advance has been reduced, particularly in the range of operating conditions corresponding to the 7-mode test procedure in effect at that time. As shown in Table 4-29, an electric assist heating unit was added in 1974 to provide additional HC control by accelerating the warmup of the thermostatic choke spring for ambient temperatures above about 60°F. With the advent of more stringent emission regulations in 1972, Ford reduced the carburetor venturi diameter to improve the fuel atomization and fuel/air mixture preparation process.

The Ford model 2150-2V carburetor used in 1975 and 1976 represents another modification of the basic 2100 series design. Except for a larger venturi diameter, this carburetor is identical to the unit described in Section 4.3.3.4 for the 2.8-liter engine.

For acceptable vehicle driveability and emission characteristics during engine warmup, the idle speed of the engine when cold is increased from curb idle to 1400 or 2000 rpm, depending upon the particular calibration considered. However, as the engine warms up, the idle speed is reduced until curb idle is reached for the fully warmed-up engine. As shown in Table 4-27, the curb idle speed of the engine is increased slightly in 1975 as a means of reducing idle CO emissions, particularly in vehicles with A/C.

4.3.5.4.2 Carburetor Calibration

Carburetor calibration data for the 1974-1976 certification vehicles are listed in Table 4-30, which shows the air/fuel ratio at idle, off idle, part-throttle, and WOT (Refs. 4-43 through 4-48). In general, the

TABLE 4-30. CERTIFICATION CALIBRATION DATA: FORD 351W ENGINE

Engine/Vehicle Parameter	Model Year and Calibration Standard																					
	1976 49 States				1976 California			1975 49 States						1975 California		1974 49 States					1970	1969
Vehicle Model	Mo[a]	G[b]	G[b]	G[b]	Mo[a]	G[b]	Mo[a]	Ma[c]	Ma[c]	Ma[c]	Ma[c]	T[d]	T[d]	Ma[c]	Ma[c]	T[d]	Fo[e]	Fo[e]	Mt[f]	Fo[e]	Mu[g]	Co[h]
Certification Calibration	6-12H -RO	6-12H -RO	6-12 -RO	6-12H -R1	5-12N -R55	6-12N -R7	5-12N -R55	5-12A -R3	5-12A -R3	5-12A -R5	5-12A -R5	5-12G -R4	5-12G -R4	5-12N -R5	5-12N -R5	4-12 -RO	4-12B -RO	4-12D -RO	4-12E -RO	4-12B -R5	In-	In-
Vehicle Inertia Weight, lb	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4500	4500	4000	4000	4500	5000	4500	5000	5000	-	-
Rear Axle Ratio	3.07	3.00	2.75	2.75	3.07	2.75	3.00	3.00	3.00	3.07	3.07	3.00	3.00	3.07	3.07	2.75	2.75	3.25	3.25	2.75	-	-
Catalyst	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
Carburetor Calibration, A/F																						
Idle	14.9	14.9	14.9	14.9	15.4	11.6	15.4	14.7	14.7	15.1	15.1	13.9	13.9	15.4	15.4	15.1	15.1	15.1	15.1	15.1	12.5	12.5
Off Idle	14.7	14.7	14.7	14.7	14.3	13.7	14.3	14.5	14.5	14.9	14.9	14.1	14.1	14.3	14.3	16.0	16.0	16.0	16.0	16.0	-	-
Part Throttle	15.2	15.2	15.2	15.2	15.8	13.9	15.8	16.0	16.0	16.9	16.9	16.2	16.2	15.9	15.9	16.7	16.7	16.7	16.7	16.7	-	-
WOT	12.0	12.0	12.0	12.0	12.0	12.3	12.0	12.6	12.6	13.2	13.2	12.8	12.8	12.1	12.1	14.1	14.1	14.1	14.1	14.1	-	-
Basic Timing, crankshaft deg BTC	8	8	8	11	6	10	6	4	4	4	4	6	6	6	6	10	6	6	6	6	6	6
Centrifugal Advance, crankshaft deg																						
1000 rpm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	3	2
1500 rpm	12	12	12	12	3	8.5	3	3	3	3	3	5	5	2.5	2.5	10	10	10	10	10	11	10.5
2000 rpm	16	16	16	16	7	10.5	7	9	9	9	9	9	9	6.5	6.5	14.5	14.5	14.5	14.5	14.5	14	13
3000 rpm	21	21	21	21	13	15	13	16	16	16	16	16	16	13.5	13.5	22.5	22.5	22.5	22.5	22.5	18	17.5
4000 rpm	27	27	27	27	19	20	19	23	23	23	23	23	23	19	19	30.5	30.5	30.5	30.5	30.5	22	22
5000 rpm	31	31	31	31	20	24.5	20	30	30	30	30	30	30	20	20	35.5	35.5	35.5	35.5	35.5	-	-
Vacuum Advance, crankshaft deg																						
5 in. Hg	8	8	8	8	1	3	1	1.5	1.5	4.5	4.5	1	1	1	1	0	0	0	0	0	0.5	1
6 in. Hg	13	13	13	13	1.5	7	1.5	2.5	2.5	8	8	2.5	2.5	1.5	1.5	4	4	4	4	4	1.0	4
8 in. Hg	17	17	17	17	5	14	5	7	7	14	14	7	7	5	5	10	10	10	10	10	1.0	11
10 in. Hg	22	22	22	22	10	19	10	12	12	19	19	12	12	10	10	15	15	15	15	15	4	13.5
12 in. Hg	24	24	24	24	14	22	14	16	16	22	22	16	16	14	14	18	18	18	18	18	8	13.5
15 in. Hg	24	24	24	24	19	24	19	21	21	24	24	21	21	19	19	23	23	23	23	23	14	13.5
20 in. Hg	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	23	23	23	23	23	19	13.5
EGR Valve Calibration																						
Signal Pressure To Open, in. Hg	2.5	2.5	2.5	2.5	2.5	-	2.5	2.9	2.9	2.9	2.9	3.5	3.5	2.5	2.5	3.6	3.6	3.6	2.9	3.6	0	0
Flow at 12-in. Hg, cfm	22	22	22	22	24	-	24	6.1	6.1	6.1	6.1	10	10	24	24	13.3	13.3	13.3	22	13.3	0	0
Fuel Economy, mpg																						
City	14	14	13	14	13	13	12	12	12	12	11	11	11	9	9	10.8[i]	10.7[i]	10.7[i]	9.9[i]	10.4[i]	-	-
Highway	17	17	18	19	17	15	16	16	16	16	18	16	17	12	14	-	-	-	-	-	-	-
Exhaust Emissions, g/m																						
HC	0.5	0.5	0.7	0.8	0.4	-	0.6	1.3	0.9	1.2	1.2	0.9	1.0	0.9	0.4	2.6[i]	2.7[i]	2.7[i]	2.5[i]	2.2[i]	-	-
CO	6	3	8	11	6	-	6	15	13	14	10	5	5	9	6	30[i]	30[i]	27[i]	35[i]	28[i]	-	-
NO_x	2.3	2.9	2.8	1.9	1.5	-	1.1	2.5	2.2	2.4	2.8	2.6	2.7	1.3	1.5	3.0[i]	2.6[i]	3.0[i]	2.5[i]	2.7[i]	-	-

[a] Monarch
[b] Granada
[c] Maverick
[d] Torino
[e] Ford
[f] Montego
[g] Mustang
[h] Cougar
[i] 1972 FTP

air/fuel ratio shows a declining trend between 1974 and 1976, which is consistent with the trends observed on the previously examined 2.3- and 2.8-liter 250-CID engines. According to Ford, the carburetor settings used for the various model years have been determined by optimizing the total engine system to meet the prevailing emission standards with acceptable driveability, durability, and fuel consumption characteristics.

4.3.5.5 Ignition System

4.3.5.5.1 Design Features

While the Ford breakerless ignition system was used in most 1974 production engines and in all 1975 and 1976 certification and production vehicles incorporating the 351W engine, the 1974 certification vehicles listed in Table 4-30 were equipped with a conventional breaker-point ignition system. As previously described (Section 4.3.3.5), the breakerless system, while retaining most features of the conventional system, employs a unique armature and magnetic pickup coil assembly in the distributor and a solid-state amplifier module.

The vacuum advance unit used in the 1969 and 1974-1976 model year 49-states certification vehicles considered in Table 4-30 is of the single diaphragm type. Conversely, a dual diaphragm design is employed in the 1975 and 1976 California vehicles, providing spark retard of 6 deg at curb idle and during closed throttle vehicle coast down. Both distributor configurations are described in Section 4.3.2.5.

4.3.5.5.2 Spark Timing Control Devices

The ignition system used in 1974 incorporates a distributor vacuum control valve and SDV (Table 4-29). As discussed in Section 4.3.2.6, the vacuum control valve protects the engine from overheating by increasing the spark advance when the coolant temperature exceeds about 225°F. Conversely, the SDV functions as a NO_x and HC control device which delays the spark advance during periods of vehicle acceleration, at the expense of a small loss in fuel economy.

4.3.5.5.3 Spark Advance Schedules

The centrifugal and vacuum spark advance of the 1974-1976 certification vehicles and the 1969 and 1970 in-use vehicles are listed in Table

4-30 as a function of vehicle speed and spark port vacuum (Refs. 4-43 through 4-48 and 4-53 through 4-56). To provide the basis for a meaningful discussion of the effects of spark advance on vehicle fuel economy, the average spark advance has been determined for each model year by arithmetically averaging the spark settings of the individual vehicles listed in Table 4-30. The resulting distributions are presented in Figures 4-52 and 4-53, which show the average centrifugal and vacuum spark advance as a function of model year, engine speed, and port vacuum. It should be noted that the 1971-1973 model years were not examined in this study, as indicated by the dashed portions of the individual curves.

In the low-speed regime, the centrifugal spark advance remains essentially constant between 1969 and 1974. Conversely, at high speeds the centrifugal advance of the 1974 model 49-states vehicles is about 5 deg higher than in 1969. While the centirfugal advance is generally reduced by several degrees in 1975, Ford has been able to implement a substantial centrifugal spark advance increase in its 1976 model year 49-states vehicles by simultaneously optimizing air/fuel ratio, spark timing, and EGR flow and by taking full advantage of the emission abatement capability of the catalyst.

Except for the low-speed regime, the centrifugal advance of the 1975 California vehicles is lower than for the 49-states vehicles, reflecting the more stringent California emission standards. While the emission standards remained constant between 1975 and 1976, the centrifugal advance of the 1976 California engines was slightly reduced by Ford relative to 1975, as part of the overall optimization process of the total engine system with respect to emissions, fuel economy, and driveability (Ref. 4-58).

The vacuum advance curves shown in Figure 4-53 indicate a substantial increase in the vacuum advance between 1970 and 1974, except for the low vacuum regime, followed by a reduction in 1975 and another increase in 1976. Like the centrifugal advance characteristics discussed, the vacuum advance of the California vehicles is generally lower than that of the 49-states vehicles. Again, an increase is shown in 1976 which more than compensates for the corresponding reduction in centrifugal advance. It should be noted, however, that part of the observed variation in the vacuum advance shown in Figure 4-53 might be caused by modifications in the location

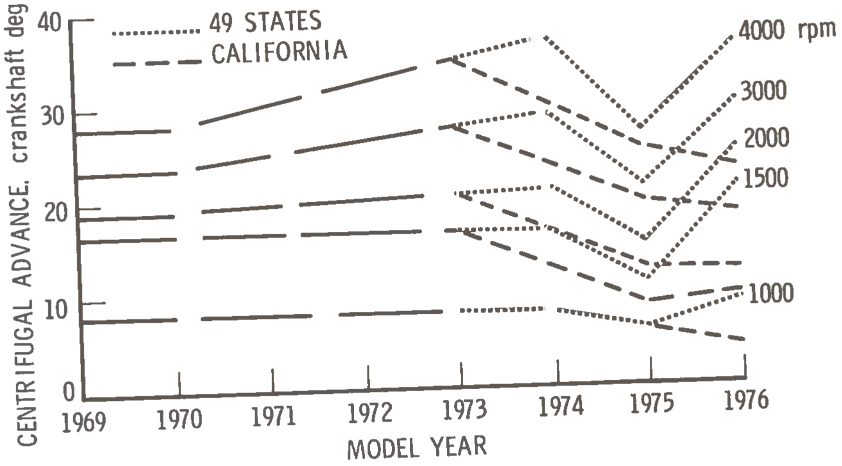


FIGURE 4-52. CENTRIFUGAL SPARK ADVANCE SCHEDULE: 1975 AND 1976 FORD 351W ENGINE WITH AUTOMATIC TRANSMISSION AND CATALYST

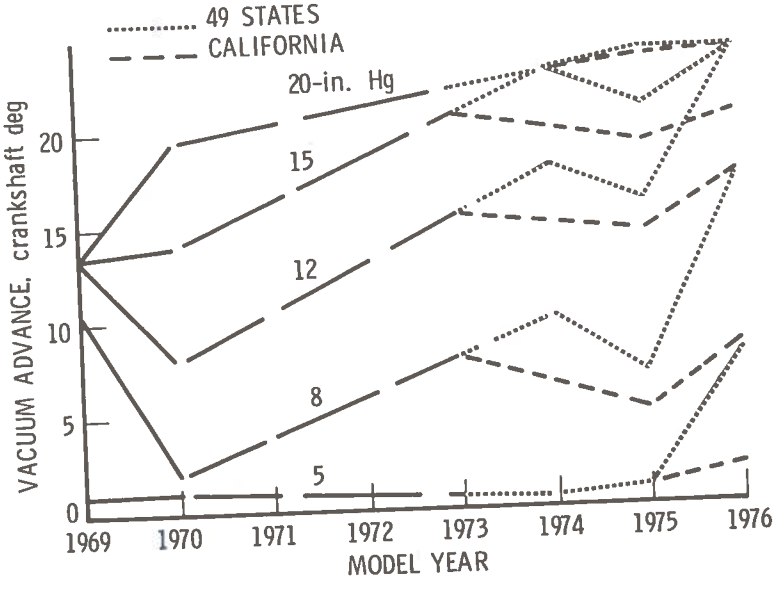


FIGURE 4-53. VACUUM SPARK ADVANCE SCHEDULE: 1975 AND 1976 FORD 351W ENGINE WITH AUTOMATIC TRANSMISSION AND CATALYST

of the carburetor spark port relative to the throttle plate. However, these modifications are quite small and should have little impact on this investigation (Ref. 4-53).

The effect of spark advance variation on vehicle fuel economy is discussed in Section 4.3.5.9.

4.3.5.6 Exhaust Gas Recirculation

As shown in Table 4-39, all 1974-1976 model year vehicles incorporating the 351W engine are equipped with an EGR system for NO_x control. The 49-states vehicles use a port vacuum-controlled EGR system in 1974 and 1975, while a backpressure-controlled EGR system is employed in 1976. Conversely, the 1975 and 1976 California vehicles incorporate a venturi vacuum-controlled EGR system with vacuum amplifier. The design and operational characteristics of these systems are described in Section 4.3.2.6.

A modulating EGR flow control valve is used in 1974, whereas a poppet or a tapered stem valve is used in 1975 and 1976. Like the poppet valve described in Section 4.3.2.6, the modulating EGR valve uses a disc to control the initial flow rate through the valve. In addition, the valve incorporates a pintle which restricts the flow area at high vacuum levels and reduces the EGR flow rate through the valve to provide better proportionality between the EGR and engine air flows. The maximum EGR flow is controlled by means of an orifice plate inserted in the mounting flange. The poppet and tapered stem type valves are similar to the configurations previously described for the 2.3- and 2.8-liter engines.

The vacuum signal which operates the EGR flow valve is controlled by a water temperature sensing valve, which is closed until the coolant reaches a temperature of about 95°F. Below that temperature, the vacuum supply to the EGR valve is interrupted, and the EGR flow control valve remains closed to improve the driveability of the vehicle during engine warmup.

4.3.5.6.1 EGR Valve Calibration

The available EGR valve calibration data are listed in Table 4-30 in terms of the signal pressure required for initial valve opening and the volume flow through the valve corresponding to a signal pressure of 12-in. Hg.

As previously noted, the available data are not sufficient to determine the instantaneous EGR flow rate for the various engine operating conditions of the Federal Driving Cycle. However, the data are useful to draw qualitative conclusions regarding the use of EGR in the various certification vehicles considered in this study.

As indicated in Table 4-14, the EGR flow of the 1975 model 49-states vehicles is much lower than in 1974. While the NO_x emission standards remained nearly constant between 1974 and 1976, the use of less EGR was permissible in 1975 because of the simultaneous decline in spark advance, which, by itself, resulted in lower NO_x emissions. Conversely, spark timing was advanced again in 1976 and this required the use of more EGR to meet the NO_x emission standards.

Relative to the 1975 49-states calibration, the 1975 California vehicles use substantially higher EGR flow rates, reflecting the more stringent California NO_x standard. Unlike the 49-states vehicles, the 1976 California vehicles use identical EGR flow rates in 1975 and 1976, which is reasonable considering the small spark advance differences used for the two model years.

4.3.5.7 Thermactor Exhaust Emission Control System

As shown in Table 4-29, the thermactor system was introduced in 1975 and has been retained in 1976. The basic system consists of a positive displacement air pump, a check valve, and an ABPV. Additional control devices are incorporated in some of the vehicles, including a thermactor delay valve, a cold lockout air cleaner TAV switch, and a floorpan-mounted thermal switch. The basic system and the optional devices are functionally identical to the configurations described for other Ford engines in Section 4.3.2.7 and 4.3.3.7. The air pump used in conjunction with the 351W engine is identical to the unit previously discussed, except that a higher pulley drive ratio of 1.96 is used, which is consistent with the higher exhaust gas flow rates of the engine.

4.3.5.8 Catalytic Converter

All 1975 and 1976 model 49-states and California vehicles are equipped with a single monolithic precious metal catalyst of the type described in Section 4.3.2.8. The substrate used in the California vehicles is oval shaped (3.66 x 6.64 inches) with a length of 6 inches and a total active metal loading of 0.11 troy oz (66 percent platinum and 34 percent palladium). The 49-states vehicles use either the same substrate with a noble metal loading of 0.10 troy oz or a smaller catalyst (4.66-inch diameter) with a precious metal loading of only 0.04 troy oz.

4.3.5.9 Fuel Economy and Emissions

The city and highway fuel economy and emission data of the certification vehicles with automatic transmission incorporating the 351W engine are listed in Table 4-29 (Refs. 4-43 through 4-48 and 4-21). For an evaluation of the fuel economy trends as affected by the modifications in the calibration of the engine, the city fuel economy data have been normalized to a common vehicle inertia weight of 4000 pounds and a common rear axle ratio of 2.75, using the normalization method described in Section 3.

The normalized average fuel economy data are presented in Figure 4-54 for the 1973-1976 certification vehicles and for a number of 1969-1972 in-use vehicles which were tested in an "as-is" condition as part of the EPA emission surveillance test program (Refs. 4-53 through 4-56). Again, the 1973 and 1974 data have been upgraded by 5 percent to account for the different test procedures used in 1972-1974 and in 1975/76.

The fuel economy and the average HC, CO, and NO_x emissions shown in Figure 4-55, remain nearly constant between 1969 and 1971. This period is followed by substantially lower fuel economy between 1971 and 1973, accompanied by lower HC, CO, and NO_x emissions. These changes are attributed primarily to the higher air/fuel ratio provided by the carburetor and the introduction of EGR in 1973. The use of EGR has required an increase in spark advance to counteract the concommitant reduction in the flame speed of the combustion process. Since the emissions of the 1973 vehicles were considerably below the standards, Ford has increased the spark advance of the 49-states vehicles, in 1974, which has resulted in a marked improvement in fuel economy, accompanied by slightly higher HC, CO, and NO_x emissions. To meet the more stringent 1975 emission standards, Ford has incorporated a catalyst in some of the 1975 model 49-states vehicles and has readjusted the carburetor, distributor, and EGR flow valve calibrations. As indicated in Table 4-30, the air/fuel ratio as well as the centrifugal and vacuum spark

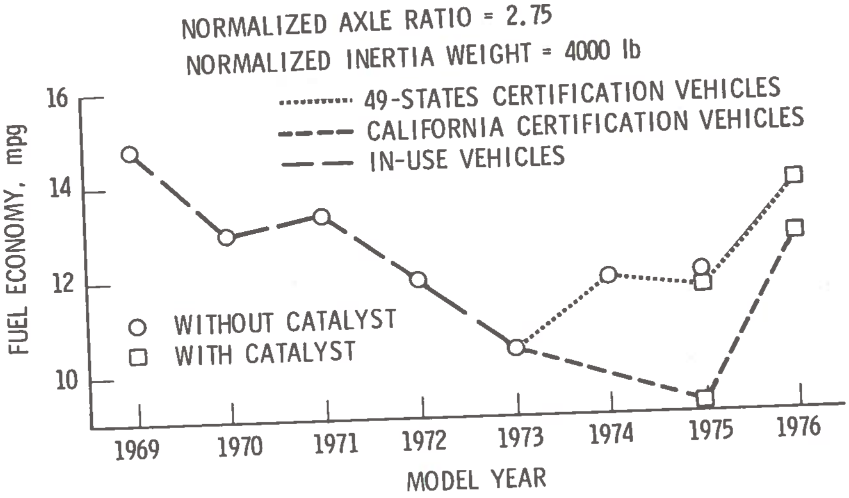


FIGURE 4-54. NORMALIZED AVERAGE CITY FUEL ECONOMY: FORD 351W ENGINE WITH AUTOMATIC TRANSMISSION; 1975 FTP

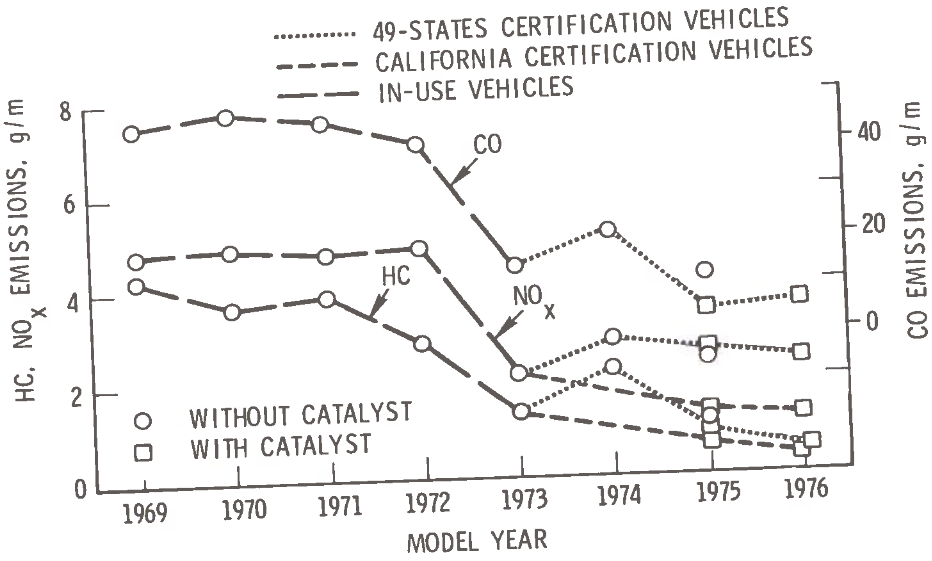


FIGURE 4-55. AVERAGE EXHAUST EMISSIONS: FORD 351W ENGINE WITH AUTOMATIC TRANSMISSION; 1975 FTP

advance are reduced in 1975. In particular, the decline in spark advance lowers the formation of NO_x in the combustion chamber, permitting a reduction in EGR, which counteracts the loss in fuel economy that would have otherwise occurred as a result of spark timing retard. Compliance with the more stringent 1975 California standards has been achieved by means of a further reduction in spark advance, combined with lower air/fuel ratios and higher EGR flow rates. As shown in Figure 4-54, these modifications are accompanied by substantial fuel economy losses.

In 1976, the calibration of the various engine components and emission control technqiues has been simultaneously optimized, resulting in significant fuel economy improvements of the 49-states and California vehicles. In particular, the spark of the 49-states vehicles has been advanced, while the air/fuel ratio has been enriched to provide optimum exhaust gas temperature conditions and species concentrations for the catalyst, as well as acceptable vehicle driveability. However, because of the advanced spark timing, more EGR is required in the 1976 model 49-states vehicles to negate any increase in NO_x resulting from the timing advance. Similar trends are obtained for the California vehicles.

In general, the highway fuel economy of the 49-states and California vehicles follows the city fuel economy trends discussed.

4.4 GENERAL MOTORS CORPORATION

4.4.1 Engine/Vehicle Configurations

Three engines consisting of an inline 4-cylinder, an inline 6-cylinder, and a V-8 have been chosen to typify the GM engine control practices since 1968. The 140-CID 4-cylinder unit is a fairly recent addition to the GM line, and the model years of interest are 1972 and 1974-1976. The remaining two engines, a 250-CID 6-cylinder and a 350-CID V-8 have a longer history and are examined for the 1967, 1970 and 1974-1976 model years.

The 4-cylinder engine has been used primarily in the Chevrolet Vega; however, it has also recently found application in the Chevrolet Monza, as well as in Vega and Monza derivatives offered by other GM divisions. The Vega and Monza currently place models in both the 2750- and 3000-pound inertia weight class. Three, four, and five speed manual transmissions are offered, as well as a three speed automatic transmission.

The 250-CID 6-cylinder engine is typically teamed with vehicles of 3500- to 4500-pound inertia weight, such as the Chevrolet Nova and the Chevelle. Manual and automatic three speed transmissions are available.

The 350-CID V-8 is used in vehicles such as the Camaro where it is rated at 4000-pound inertia weight, the Chevelle at 4500 pounds, the Impala at 5000-pounds, and the Caprice Station Wagon at 5500-pounds. An automatic and a manual three speed and a manual four speed transmission are offered with availability model dependent.

While the foregoing material refers to a GM 4-, 6-, and 8-cylinder engine, there are actually many more than these three distinct GM engines within the displacements and configurations discussed above. For example, each division of GM has its own version of the 350-CID V-8, and they often vary substantially from one another in basic design parameters such as bore and stroke, valve timing, fuel delivery systems, and the application of emission control methods and systems. Therefore, in order to limit the discussion of these engines to a tractable size, a single engine within each of the configurations introduced above has been chosen for purposes of this report. Specifically, the Chevrolet Division versions have been selected. While this is not exhaustive of all GM design approaches, it does provide a reasonable cross section of overall GM engine control practices.

4.4.2 Engine Design Features

Tables 4-31 through 4-33 present an overview of key engine design parameters and engine control approaches used in the GM engines selected (Refs. 4-59 through 4-74). For some engines, an exhaust control system designated CCS (Controlled Combustion System) is listed. In general, the CCS consists of changes in internal engine component design, altered carburetor calibrations, and changes in ignition timing control. Included in the category of ignition timing control are systems such as TCS and devices which provide on-off modulation of vacuum ignition advance by engine coolant temperature. As specific systems and devices of this type are not always a part of CCS, their implicit inclusion could cause confusion when refering to these tables. For this reason, the presence of TCS or a TVS is listed explicitly for all engine-model year combinations which use these systems and

TABLE 4-31. ENGINE SPECIFICATIONS: GM 140-CID ENGINE

Engine Parameter	Model Year							
	1976		1975		1974		1972	
	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4		4	
Bore, in.	3.5		3.5		3.5		3.5	
Stroke, in.	3.625		3.625		3.625		3.625	
Displacement, cu in.	140		140		140		140	
Surface/Volume, 1/in.	5.97		5.97		5.97		5.97	
Compression Ratio	7.9		7.9		7.9		7.9	
Cylinder Head Type	OHC		OHC		OHC		OHC	
Advertised HP at Engine Speed, rpm	70 at 4400 (1V) 84 at 4400 (2V)	80 at 4400 (2V)	78 at 4200 (1V) 87 at 4400 (2V)	80 at 4400 (2V)	75 at 4400 (1V) 85 at 4400 (2V)		80 at 4400 (1V) 93 at 4800 (2V)	
Torque, ft-lb, at Engine Speed, rpm	107 at 2400 (1V) 113 at 3200 (2V)	100 at 2800 (2V)	120 at 2000 (1V) 122 at 2800 (2V)	116 at 2800 (2V)	115 at 2400 (1V) 122 at 2400 (2V)		121 at 2600 (1V) 121 at 3000 (2V)	
Exhaust System Type	Single		Single		Single		Single	
Combustion Chamber Configuration	Open		Open		Open		Open	
Intake Valve Diameter, in.	1.625		1.625		1.625		1.625	
Intake Valve Lift, in.	0.396		0.401 (1V) 0.408 (2V)	0.404 (2V)	0.420 (1V) 0.437 (2V)	0.420 (1V) 0.437 (2V)	0.420 (1V) 0.437 (2V)	0.437 (1V or 2V)
Exhaust Valve Diameter, in.	1.375		1.375		1.375		1.375	
Exhaust Valve Lift, in.	0.411		0.396 (1V) 0.404 (2V)	0.418 (2V)	0.430 (1V) 0.439 (2V)	0.430 (1V) 0.439 (2V)	0.430 (1V) 0.438 (2V)	0.438 (1V or 2V)
Intake Valve Opens, deg BTC	18		10 (1V) 14 (2V)	14 (2V)	10 (1V) 14 (2V)	10 (1V) 14 (2V)	10 (1V) 14 (2V)	14 (1V or 2V)
Intake Valve Closes, deg ABC	58		46 (1V) 50 (2V)	50 (2V)	46 (1V) 52 (2V)	46 (1V) 52 (2V)	46 (1V) 52 (2V)	52 (1V or 2V)
Intake Valve Duration, deg	256		236 (1V) 244 (2V)	244 (2V)	236 (1V) 246 (2V)	236 (1V) 246 (2V)	236 (1V) 246 (2V)	246 (1V or 2V)
Exhaust Valve Opens, deg BBC	56		46 (1V) 45 (2V)	45 (2V)	46 (1V) 45 (2V)	46 (1V) 45 (2V)	46 (1V) 45 (2V)	45 (1V or 2V)
Exhaust Valve Closes, deg ATC	24		2 (1V) 9 (2V)	9 (2V)	2 (1V) 9 (2V)	2 (1V) 9 (2V)	2 (1V) 9 (2V)	9 (1V or 2V)
Exhaust Valve Duration, deg	260		228 (1V) 234 (2V)	234 (2V)	228 (1V) 234 (2V)	228 (1V) 234 (2V)	228 (1V) 234 (2V)	234 (1V or 2V)
Valve Overlap, deg in.	0.428		0.047 (1V) 0.246 (2V)	0.246 (2V)	0.047 (1V) 0.246 (2V)	0.047 (1V) 0.246 (2V)	0.047 (1V) 0.246 (2V)	0.231 (1V or 2V)
Distributor Type	Breakerless; centrifugal and vacuum advance		Breakerless; centrifugal and vacuum advance		Breaker point; centrifugal and vacuum advance		Breaker point; centrifugal and vacuum advance	
Basic Ignition Advance, deg BTC[a] at Engine Speed, rpm	10 at 750 (A, 1V)[b] 8 at 700 (M, 1V)[b] 12 at 750 (A, 2V)[b] 10 at 700 (M, 2V)[b]	12 at 750 (A) 10 at 700 (M)	10 at 750 (A, 1V)[b] 8 at 700 (M, 1V)[b] 12 at 750 (A, 2V)[b] 10 at 700 (M, 2V)[b]	12 at 750 (A) 10 at 700 (M)	12 at 750 (A) 10 at 700 (M)	12 at 750 (A) 10 at 700 (M)	6 at 700 (A) 6 at 1200 (M, 2V) 6 at 850 (M, 1V)	6 at 700 (A, 1V) 10 at 700 (A, 2V) 6 at 1200 (M3, 2V) M4 6 at 850 (M3, 1V)
Idle Speed, rpm[a]	750 (A, 1V) 700 (M, 1V) 750 (A, 2V) 700 (M, 2V)	750 (A) - (M)	750 (A, 1V) 700 (M, 1V) 750 (A, 2V) 700 (M, 2V)	750 (A) 1200 (M)	750 (A) 1000 (M)		700 (A) 1200 (M, 2V) 850 (M, 1V)	700 (A) 1200 (M3, 2V, M4) 850 (M, 1V)
Fast Idle Speed, rpm[a]	-		2200 (1V, A) 2000 (1V, M) 1600 (2V)	1600	2200 (A) 2000 (M)			-
Intake Air Temperature Control	Thermostatic		Thermostatic		Thermostatic		Thermostatic	
Fuel System Type	1V or 2V	2V	1V 2V	2V	1V 2V	1V 2V	1V 2V	1V or 2V
Fuel Metering Method	Fixed orifice		Fixed orifice		Fixed orifice		Fixed orifice	
Enrichment Method	Power valve (1V) Vacuum diaphragm (2V)		Power valve (1V) Vacuum diaphragm (2V)		Power valve (1V) Vacuum diaphragm (2V)		Power valve (1V) Vacuum diaphragm (2V)	
Choke Type	Automatic		Automatic		Automatic		Automatic	
Carburetor Venturi Diameter, in.	1.219 (1V) 1.26/1.417 (2V)		1.219 (1V) 1.26/1.417 (2V)		1.219 (1V) 1.26/1.417 (2V)		1.219 (1V) 1.094/ - (2V)	
Carburetor Maximum Air Flow at Intake Vacuum, in. Hg	12 lb/min at 3 16.3 lb/min at 2		166 cfm at 3 225 cfm at 2		166 cfm at 3 225 cfm at 2		166 cfm at 3 274 cfm at 3	
Emission Control Systems	1V: AIR, EGR, EVAP, PCV, TCS[c] 2V: CAT[d], EGR, EVAP, PCV	2V: AIR, CAT[e], EGR, EVAP, PCV	1V: AIR, EGR, EVAP, PCV, TCS[c] 1V or 2V: CAT[d], EGR, EVAP, PCV	2V: AIR, CAT[e], EGR, EVAP, PCV	1V or 2V: CCS, EGR, EVAP, PCV, TCS[c, f]	1V or 2V: CCS, EGR, EVAP, PCV, TCS[c]	1V: CCS, EVAP, PCV, TCS 2V: AIR, EVAP, PCV, TCS	1V or 2V: AIR, EVAP, PCV, TCS
Emission Control Devices	1V: Sec. choke PO, TCS TVS[c] 2V: Sec. choke PO	Secondary choke PO Thermal check & delay	1V: Sec. choke PO, TCS TVS[c] 1V or 2V: Sec. choke PO, Ther. check and delay[g]	Secondary choke PO Thermal check and delay	TCS TVS[c, f]	TCS TVS[c]	TCS TVS	

[a] A = automatic transmission; M = manual transmission

[b] Add 2 deg for A/C

[c] Manual transmission only

[d] Catalyst volume is 160 cu in.

[e] Catalyst volume is 260 cu in.

[f] 2V carburetor only

[g] Automatic transmission only

TABLE 4-32. ENGINE SPECIFICATIONS: GM 250-CID ENGINE

Engine Parameter	Model Year											
	1976			1975			1974		1970		1967	
	49 States			49 States								
	No. 1	No. 2	California	No. 1	No. 2	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	6			6			6		6		6	
Bore, in.	3.875			3.875			3.875		3.875		3.875	
Stroke, in.	3.53			3.53			3.53		3.53		3.53	
Displacement, cu in.	250			250			250		250		250	
Surface/Volume, 1/in.	6.63	6.57	6.63	7.21	6.38	7.21	7.01		-		-	
Compression Ratio	8.28	8.18	8.28	8.22	7.99	8.22	8.25		8.5		8.5	
Cylinder Head Type	OHV			OHV			OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	105 at 3800			105 at 3800			100 at 3600		155 at 4200		155 at 4200	
Torque, ft-lb, at Engine Speed, rpm	185 at 1200			185 at 1200			175 at 1800		235 at 1600		235 at 1600	
Exhaust System Type	Single			Single			Single		Single		Single	
Combustion Chamber Configuration	Wedge			Wedge			Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.72			1.72			1.72		-		-	
Intake Valve Lift, in.	0.381			0.381			0.381		-		-	
Exhaust Valve Diameter, in.	1.50			1.50			1.50		-		-	
Exhaust Valve Lift, in.[a]	0.398	0.381	0.398	0.398	0.381	0.398	0.381 (A) 0.398 (M)	0.398	-		-	
Intake Valve Opens, deg BTC	29	25	29	29	25	29	25		-		-	
Intake Valve Closes, deg ABC	53	57	53	53	57	53	57		-		-	
Intake Valve Duration, deg	262			262			262		-		-	
Exhaust Valve Opens, deg BBC[a]	58	56	58	58	56	58	56 (A) 54 (M)	54	-		-	
Exhaust Valve Closes, deg ATC[a]	32	26	32	32	26	32	26 (A) 36 (M)	36	-		-	
Exhaust Valve Duration, deg[a]	270	262	270	270	262	270	262 (A) 270 (M)	270	-		-	
Valve Overlap, deg in.[a]	0.686	0.289	0.686	0.686	0.289	0.686	0.289 (A) 0.686 (M)	0.686	-		-	
Distributor Type	Breakerless; centrifugal & vacuum adv.			Breakerless; centrifugal & vacuum adv.			Breaker point; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.	
Basic Ignition Advance, deg BTC at Engine Speed, rpm[a]	10 (A) 6 (M)	8	10	10	8	10	8 at 600 (A) 8 at 850 (M)		4 at - (A) 0 at - (M)		4 at 500, w/o AIR 4 at 500 (A), with AIR 4 at 700 (M), with AIR	
Idle Speed, rpm[a]	550(A) 850(M)	600	600	550(A) 850(M)	600(A) -	600 (A) -	600 (A) 850 (M)		-		-	
Fast Idle Speed, rpm	-			-			-		2400		-	
Intake Air Temperature Control	Thermostatic			Thermostatic			-		-			
Fuel System Type	1-V carburetor			1-V carburetor			1-V carburetor		1-V carburetor		1-V carburetor	
Fuel Metering Method	Fixed orifice with metering rod			Fixed orifice with metering rod			Fixed orifice with metering rod		Fixed orifice with metering rod		Type 1: Fixed orifice Type 2: Fixed orifice with metering rod	
Enrichment Method	Mechanical and vacuum			Mechanical and vacuum			Mechanical and vacuum		Mechanical and vacuum		Mechanical & vacuum Type 1: power valve Type 2: metering rod	
Choke Type	Automatic			Automatic			Automatic		Automatic		Automatic	
Carburetor Venturi Diameter, in.	1.3125			1.3125			1.3125		1.6875		Type 1: 1.5625 Type 2: 1.6875	
Carburetor Maximum Air Flow at Intake Vacuum, in. Hg	14.4 lb/min at 1.5			213 cfm at 3			-		-		-	
Emission Control Systems	CAT EFE EGR EVAP PCV	CAT EGR EVAP PCV	CAT CAIR EFE EGR EVAP PCV	CAT EFE EGR EVAP PCV	CAT EGR EVAP PCV	CAT CAIR EFE EGR EVAP PCV	AIR[c] CCS[b] EGR[b] EGR[c] EVAP PCV TCS[c]	AIR EGR EVAP PCV TCS[c]	CCS PCV	AIR EVAP PCV	-	AIR PCV
Emission Control Devices	EFE TVS Sec. choke PO	EGR TVS	EFE TVS EGR TVS Secondary choke PO	EFE TVS Sec. choke PO	EGR TVS	EFE TVS EGR TVS Secondary choke PO	EGR TVS TCS time delay TCS TVS[c]					

[a] A = automatic transmission; M = manual transmission

[b] Automatic transmission only

[c] Manual transmission only

TABLE 4-33. ENGINE SPECIFICATIONS: GM 350-CID ENGINE

Engine Parameter	Model Year									
	1976		1975		1974		1970		1968	
	49 States	California	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	8		8		8		8		8	
Bore, in.	4.0		4.0		4.0		4.0		4.0	
Stroke, in.	3.48		3.48		3.48		3.48		3.48	
Displacement, cu in.	350		350		350		350		350	
Surface/Volume, 1/in.	6.29		6.27		6.27		6.27		6.27	
Compression Ratio (CR)	8.21		8.2		8.2		8.0 9.0	10.25 11.00	-	
Cylinder Head Type	OHV		OHV		OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	145 at 3800 (2V) 155 at 3800 (4V)	155 at 3800 (2V)	145 at 3800 (2V) 155 at 3800 (4V)	155 at 3800 (4V)	145 at 3600 (2V) 160 at 3800 (4V)	160 at 3800 (4V)	215 at 4400 (2V) CR=8.0 250 at 4800 (2V) CR=9.0 300 at 4800 (4V) CR=10.25 350 at 4800 (4V) CR=11.0			
Torque, ft-lb, at Engine Speed, rpm	250 at 2200 260 at 2400	260 at 2400 (2V)	250 at 2200 (2V) 260 at 2400 (4V)	260 at 2400 (4V)	250 at 2200 (2V) 250 at 2400 (4V)	250 at 2400 (4V)	320 at 2400 (2V) CR=8.0 245 at 2400 (2V) CR=9.0 380 at 3200 (4V) CR=10.25 380 at 3600 (4V) CR=11.0			
Exhaust System Type	Single		Single		Single		Single and dual		-	
Combustion Chamber Configuration	Wedge		Wedge		Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.94		1.94		1.94		-		-	
Intake Valve Lift, in.	0.384		0.384		0.384		-		-	
Exhaust Valve Diameter, in.	1.50		1.50		1.50		-		-	
Exhaust Valve Lift, in.	0.404		0.404		0.404		-		-	
Intake Valve Opens, deg BTC	14		14		14	19	-		-	
Intake Valve Closes, deg ABC	64		64		64	70	-		-	
Intake Valve Duration, deg	258		258		258	269	-		-	
Exhaust Valve Opens, deg BBC	63		63		63	65	-		-	
Exhaust Valve Closes, deg ATC	26		26		26	38	-		-	
Exhaust Valve Duration, deg	269		269		269	283	-		-	
Valve Overlap, deg in.	0.355		0.355		0.355	0.982	-		-	
Distributor Type	Breakerless; centrifugal & vacuum adv.		Breakerless; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.	
Basic Ignition Advance, deg BTC at Engine Speed, rpm[a]	6 at 600 (2V) 8 at 600 (4V)	6 at 600 (4V)	6 at 600 (2V, A) 6 at 800 (2V, M) 8 at 600 (4V, A) 6 at 800 (4V, M)	6 at 600 (4V)	8 at 600 (A) 0 at 900 (2V, M) 8 at 900 (4V, M)	8 at 600 (A) 4 at 900 (M)	4 at - (A) 0 at - (M)		-	
Idle Speed, rpm[a]	600 (A) 800 (M)	600 (A)	600 (A) 800 (M)	600 (A)	600 (A) 900 (M)		-		-	
Fast Idle Speed, rpm	-		-		-		2400		-	
Intake Air Temperature Control	Thermostatic		Thermostatic							
Fuel System Type	2V or 4V carburetor	4V carburetor	2V or 4V carburetor	4V carburetor	2V or 4V carburetor	4V carburetor	2V or 4V carburetor		-	
Fuel Metering Method	Fixed orifice (2V) Meter rod/jet (4V)		Fixed orifice (2V) Meter rod/jet (4V)		Fixed orifice (2V) Meter rod/jet (4V)		Fixed orifice (2V) Meter rod/jet (4V)		-	
Enrichment Method	Vacuum power piston		Vacuum power piston		Vacuum power piston		Vacuum power piston			
Choke Type	Automatic		Automatic		Automatic		Automatic			
Carburetor Venturi Diameter, in.	1.188 (2V) 1.219/2.25 (4V)		1.188 (2V) 1.219/2.25 (4V)		1.188 (2V) 1.219/2.25 (4V)		1.6875 (2V) 1.375/2.25 (4V)			
Carburetor Maximum Air Flow at Intake Vacuum, in. Hg	18.6 lb/min at 1.5 58.5 lb/min at 1.5		340 cfm at 3 (2V) 820 cfm at 1.5 (4V)		340 cfm at 3 (2V) 820 cfm at 1.5 (4V)		-		-	

Engine Parameter	1976			1975			1974			1970	1968
Emission Control Systems	49 States		CA	49 States		CA	49 States		CA		
	2V	4V	4V	2V	4V	4V	2V	4V	4V		
	CAT EFE EGR EVAP PCV	CAT EGR EVAP PCV	CAT CAIR EFE EGR EVAP PCV	CAT EFE EGR EVAP PCV	CAT CAIR EFE EGR EVAP PCV	CAT CAIR EFE EGR EVAP PCV	AIR EGR EVAP PCV	AIR[b] CCS[c] EGR EVAP PCV TCS[b]	AIR EGR EVAP PCV TCS[b]		
Emission Control Drvices	EFE TVS EGR TVS	EGR TVS	EFE TVS EGR TVS	EFE TVS EGR TVS	EFE TVS EGR TVS	EFE TVS EGR TVS	EGR TVS	EGR TVS TCS TVS[b]	EGR TVS TCS TVS[b]		

[a] A = automatic transmission; M = manual transmission

[b] Manual transmission only

[c] Automatic transmission only

devices. In effect, this practice provides a somewhat more narrow definition of CCS than used by GM; however, clarity is improved for purposes of this report.

4.4.3 GM 140-CID Engine

4.4.3.1 Engine Modifications

For the four model years presented in Table 4-31, there has been little change in the combustion chamber design of the 140-CID overhead cam engine. Compression ratios have been held at 7.9:1 for all four years, and the surface-to-volume ratio of the open combustion chamber configuration has remained at 5.97/inch.

The single area showing some diversity in combustion chamber configuration has been concerned with intake and exhaust valve timing. As seen in Table 4-31, valve timing of engines with a two-venturi carburetor and those constructed for sale in California generally differ, except for 1974 and 1976, from engines with a single-venturi carburetor and those built to comply with 49-states standards.

For example, all 1972 California engines and the two-venturi carburetor equipped 49-states engine show approximately five times the valve overlap of the 1972 single-venturi 49-states engine. For the California model, it is possible that valve overlap was included to aid control of NO_x. However, since the 49-states two-venturi unit uses identical valve timing with no 1972 49-states NO_x requirement, it is likely the more extreme valve overlap design was primarily intended to aid in the control of HC.

With the introduction of 49-states NO_x standards and EGR in 1973 and their continuation during 1974, further changes in valve timing have been incurred. As seen in Table 4-31, relaxation of valve overlap has been allowed in the 1974 single-venturi carburetor equipped engines offered for sale in California. This is directly attributed to the use of EGR to meet the more stringent California NO_x standard.

For the 1975 model year, nearly the same California-49-states dichotomy in valve timing noted in 1972 has reappeared. While valve overlap on 49-states engines expressed in terms of degree-inches has remain unchanged, the California two-venturi carbureted engines have reverted to a valve overlap slightly in excess of the pre-EGR year of 1972. This change is attributed to a change in the manner in which NO_x control is implemented on California vehicles. As discussed later, slightly more vacuum ignition advance is used in 1975 relative to 1974, and this tends to increase NO_x above the 1974 levels. The subject valve timing change to more overlap and a slightly increased 1975 EGR rate provides the increased change dilution required to maintain NO_x emissions at or below the required level.

For 1976, the valve timing schedules have been standardized, thereby eliminating differences between the 49-states and California calibrations, as well as between one-venturi and two-venturi versions of the subject engine. As shown in Table 4-31, the additional overlap is gained by using both an advanced intake valve opening and a delayed exhaust valve closing.

4.4.3.2 Intake System

As part of the CCS mentioned previously, GM has included a thermostatically controlled air cleaner for all model years of the 140-CID engine, as shown in Table 4-1. The so-called ThermAC system is designed to maintain air entering the carburetor at approximately 100°F when underhood temperatures are less than 100°F. By keeping carburetor intake air at 100°F, the carburetor can be calibrated leaner in order to reduce HC and CO emissions, while retaining good vehicle driveability during warmup.

The ThermAC system consists of a heat stove, a conventional snorkel-type air cleaner, a vacuum diaphragm, a damper door, a bimetallic sensor, and connecting hoses. The heat stove supplies air heated by the exhaust manifold to the snorkel of the air cleaner. Heated air is supplied via ducting connected to the snorkel at its approximate midpoint, leaving the normal entry area of the snorkel free to accept ambient intake air. The damper door is positioned inside the snorkel of the air cleaner in a manner that allows it to control the source of air provided to the carburetor, depending on damper door position. Extreme positions of the door supply either heated or ambient air to the carburetor, with in-between positions providing mixes of air from the two sources. The vacuum diaphragm working against a spring is used to control door position. Temperature-modulated control of the diaphragm is in turn provided by a bimetallic sensor located on the "clean" side of the air cleaner with temperature modulation of vacuum implemented by a needle valve controlled vacuum leak in the vacuum line supplying the diaphragm.

4.4.3.3 Carburetor

4.4.3.3.1 Design Features

As indicated in Table 4-31, the GM 140-CID engine has been fitted with either a single- or a double-venturi carburetor for the 1972-1976 period. For 1975 and 1976, only the double-venturi version is available in California; however, in previous years single- and double-venturi carburetors have been offered nationwide.

Both carburetors use conventional float systems consisting of a fuel inlet needle controlled by a float and level assembly. Idle circuits for both carburetors are also conventional in design and are implemented as a bypass system with idle air/fuel mixture discharged below the throttle plate. The mixture is prepared by a series of idle air bleeds which introduce air into idle passages containing flowing fuel. Off-idle or idle transfer ports are positioned slightly above the primary throttle plate and provide additional air/fuel mixture as they are uncovered by the throttle during part-throttle operation. These ports serve as additional air bleeds during normal idle operation. On both carburetors, idle mixture adjustment screws are locked by means of limiter caps after flow tests during carburetor manufacture.

The main metering systems in both carburetors are similar and are of fixed orifice design. The single-venturi carburetor employs boost venturies for precise metering of the air/fuel mixture, and both carburetors have vacuum-operated power valves to provide primary power enrichment. On the two-venturi carburetor, the secondary venturi throttle plate starts to open when the primary plate is open approximately 45 deg. Additional air/fuel mixture is then provided via secondary transfer ports similar to the idle transfer ports located in the primary system. Further opening of the throttle plates initiates operation of the secondary main metering system, which is similar to the primary main metering system.

An air velocity operated secondary power enrichment system is provided on the two-venturi carburetor. Secondary enrichment is implemented with a fixed orifice, air bleed mixing system which begins operation for a nearly wide open position of the secondary throttle.

Choke systems on both carburetors are controlled by a thermostat using a bimetallic spring acting against a diaphragm, actuated by manifold vacuum. On the single-venturi carburetor, exhaust gas is used to heat the thermostat; however, the two-venturi unit uses engine coolant flowing through the choke water cover as a choke heating device.

A secondary choke pulloff is used in 1975 and 1976 with both carburetors. The system is designed to fully open the choke when engine coolant reaches a specified temperature. Actuation temperature is 120 ±7°F for single-venturi carburetor engines teamed with manual transmissions and 93 ±7°F for all other 140-CID engines. System hysteresis is approximately 17°F.

Except for the 1976 manual transmission, non-A/C two-venturi engines, idle stop solenoids are used on both the single- and double-venturi carburetors to close the throttle plates and prevent dieseling when the ignition is shut off.

On carburetors intended for use on vehicles equipped with A/C, a hot idle compensator consisting of a bimetallic actuated air bleed valve is an integral part of the carburetor design. The valve opens at a predetermined carburetor temperature and allows additional air to bleed into the carburetor beneath the throttle plate in order to lean excessively rich air/fuel mixtures associated with hot idle conditions. Typically, additional air in the amount of 0.15-0.2 lb/min is added to the normal air flow for carburetor temperatures above approximately 170°F-180°F.

4.4.3.3.2 Carburetor Calibration

The mean carburetor calibration data provided by GM for the 140-CID engine are listed in Table 4-34, showing the air/fuel ratio at idle, off idle, part-throttle, and WOT (Refs. 4-59 through 4-64). In general, the air/fuel ratio settings of the two-venturi 49-states carburetor remained nearly constant between 1975-1976, whereas the California calibrations were leaned out slightly in 1976, except at WOT, with little difference between the manual and automatic transmission configurations. Conversely, the air/fuel ratio of the single-venturi carburetor was reduced by about one unit in 1974 relative to 1972, followed by some additional reduction in 1975. The low idle flow rate requirement of the single-venturi 1975/1976 engines with manual transmission is attributed to the lower power consumption of the manual transmission relative to the automatic transmission.

TABLE 4-34. CERTIFICATION CALIBRATION DATA: GM 140-CID ENGINE

Engine/Vehicle Parameter	Model Year and Certification Standard																									
	1976 49 States								1976 California				1975 49 States													
Vehicle Model	V[a]	V[a]	Mo[b]	Mo[b]	V[a]	Mo[b]	V[a]	V[a]	V[a]	Mo[b]	V[a]	V[a]	V[a]	V[a]	V[a]	V[a]	V[a]	V[a,c]	V[a]	V[a]	V[a]	V[a]	V[a]	V[a]	V[a]	V[a]
Transmission Type	A3	A3	A3	M3	M4	M3	M4	M5	A3	M3	M4	M5	A3	A3	M3	M3	M4	A3	M4	M4	A3	A3	A3	M3	M4	M4
Vehicle Inertia Weight, lb	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	2750	3000	2750	3000	3000	3000	2750	3000	2750	3000	3000	2750	3000	3000
Rear Axle Ratio	2.92	2.92	3.42	2.92	2.53	3.42	2.53	2.93	2.92	3.42	2.53	2.93	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	3.42	2.92	2.92	3.42
Catalyst	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of Carburetor Venturi's	1	2	2	1	1	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2	2	2
Carburetor Calibration, A/F																										
Idle: 0.7-lb/min air flow (1V) 0.6-lb/min air flow (2V)	13.1	14.2	14.2	9.8[e]	9.8[e]	14.3	14.3	14.3	13.2	12.8	12.8	12.8	14.1	14.1	10[e]	10[e]	10[e]	14.2	10.5[e]	10.5[e]	14.0	14.0	14.0	14.0	14.0	14.0
Off Idle: 1.5-lb/min air flow (1V) 1.1-lb/min air flow (2V)	16.4	15.2	15.2	15.3	15.3	15.0	15.0	15.0	14.7	15.4	15.4	15.4	15.5	15.5	15.3	15.3	15.3	16.2	15.8	15.8	14.8	14.8	14.8	15.0	15.0	15.0
Part Throttle: 3-lb/min air flow (1V) 4-lb/min air flow (2V)	15.8	16.0	16.0	15.6	15.6	15.9	15.9	15.9	15.0	15.5	15.5	15.5	15.7	15.7	15.8	15.8	15.8	15.7	16.2	16.2	15.6	15.6	15.6	15.6	15.6	15.6
WOT at Max.: 12-lb/min air flow (1V) 16-lb/min air flow (2V)	11.5	13.5	13.5	11.6	11.6	13.4	13.4	13.4	13.2	13.3	13.3	13.3	11.6	11.6	11.6	11.6	11.6	11.5	11.9	11.9	13.7	13.7	13.7	13.7	13.7	13.7
Basic Timing, crankshaft deg BTC	10	12	12	8	8	10	10	10	12	10	10	10	10	10	8	8	8	10	8	8	12	12	12	10	10	10
Centrifugal Advance, crankshaft deg																										
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1500 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000 rpm	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
3000 rpm	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
4000 rpm	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
5000 rpm	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
Vacuum Advance, crankshaft deg																										
5 in. Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 in. Hg	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
8 in. Hg	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
10 in. Hg	18.0	18.0	18.0	18.0	18.0	18.0	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.0	18.0	18.0	18.0	18.0
12 in. Hg	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
15 in. Hg	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
20 in. Hg	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
EGR Valve Calibration																										
Signal Pressure To Open 0.01 in., in. Hg	2.0	2.5	2.5	3.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0	2.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5	2.5
Flow at 6-in. Hg, lb/min	0.4	0.64	0.64	0.11	0.11	0.4	0.4	0.4	0.73	0.64	0.64	0.64	0.4	0.4	0.11	0.11	0.11	0.4	0.17	0.17	0.64	0.64	0.64	0.4	0.4	0.4
Fuel Economy, mpg																										
City	19	20	19	21	20	22	22	22	18	18	18	18	22	19	21	20	18	19	21	20	21	23	18	23	19	21
Highway	28	29	28	30	34	31	35	36	28	27	30	30	31	25	33	31	35	28	32	29	29	27	25	37	32	31
Exhaust Emissions, g/m																										
HC	1.0	0.6	0.8	1.1	1.0	0.7	0.8	1.0	0.2	0.5	0.4	0.5	0.8	0.9	0.3	1.1	0.9	1.1	1.0	1.5	0.6	0.5	0.6	0.9	1.0	0.6
CO	12	10	11	13	10	6	7	9	4.9	5.4	5.7	6.1	7.8	9.0	9.7	11.7	12.7	13	12	13	8	8	10	12	10	6
NO_x	2.4	2.4	2.3	2.4	2.6	2.7	2.4	2.0	1.2	1.5	1.5	1.3	2.2	2.3	2.3	2.7	2.9	2.2	2.1	2.6	1.8	1.9	2.4	2.4	2.8	3

[a] Vega

[b] Monza

[c] Fuel economy and emissions represent averages of two emission data vehicles with identical calibration specifications.

[d] Calibrated to meet California emission standards

[e] At 0.4-lb/min air flow.

[f] 1972 FTP

TABLE 4-34. CONTINUED

Engine/Vehicle Parameter	Model Year and Certification Standard														
	1975 California						1974 49 States						1972 49 States		
Vehicle Model	V[a]	V[a]	V[a]	V[a]	V[a]	V[a]	V[a]	V[a]	V[a,d]	V[a]	V[a]	V[a,d]	V[a]	V[a]	V[a]
Transmission Type	A3	A3	A3	M4	M4	M4	A3	A3	A3	M3	M3	M4	A2	M4	A2
Vehicle Inertia Weight, lb	2750	3000	3000	2750	3000	3000	2750	3000	3000	2750	2750	2750	-	-	-
Rear Axle Ratio	2.92	2.92	3.42	2.92	2.92	3.42	2.92	3.36	3.36	2.53	2.92	3.36	-	-	-
Catalyst	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No
No. of Carburetor Venturi's	2	2	2	2	2	2	1	1	1	1	1	1	1	1	2
Carburetor Calibration, A/F															
Idle: 0.7-lb/min air flow (1V) 0.6-lb/min air flow (2V)	12.8	12.8	12.8	12.6	12.6	12.6	13.3	13.3	13.3	11.4[e]	11.4[e]	11.e[e]	-	-	-
Off Idle: 1.5-lb/min air flow (1V) 1.1-lb/min air flow (2V)	13.7	13.7	13.7	14.4	14.4	14.4	16.3	16.3	16.3	16	16	16	-	-	-
Part Throttle: 3-lb/min air flow (1V) 4-lb/min air flow (2V)	14.9	14.9	14.9	15.3	15.3	15.3	15.5	15.5	15.5	15.6	15.6	15.6	17.2	16.9	16.6
WOT at Max.: 12-lb/min air flow (1V) 16-lb/min air flow (2V)	13.5	13.5	13.5	13.5	13.5	13.5	11.7	11.7	11.7	12.0	12.0	12.0	12.8	12.3	11.3
Basic Timing, crankshaft deg BTC	12	12	12	10	10	10	12	12	12	10	10	10	6	6	6
Centrifugal Advance, crankshaft deg															
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1500 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	5.5	0.0
2000 rpm	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	10.0	10.0	0.0
3000 rpm	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	19.0	19.0	9.0
4000 rpm	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	26.0	26.0	20.0
5000 rpm	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	26.0	26.0	20.0
Vacuum Advance, crankshaft deg															
5 in. Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 in. Hg	3.5	3.5	3.5	3.5	3.5	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 in. Hg	10.5	10.5	10.5	10.5	10.5	10.5	4.5	4.5	4.5	4.5	4.5	4.5	4.0	4.0	4.0
10 in. Hg	18.0	18.0	18.0	18.0	18.0	18.0	11.5	11.5	11.5	11.5	11.5	11.5	11.0	11.0	11.5
12 in. Hg	24.0	24.0	24.0	24.0	24.0	24.0	18.0	18.0	18.0	18.0	18.0	18.0	17.5	17.5	17.5
15 in. Hg	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
20 in. Hg	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
EGR Valve Calibration															
Signal Pressure To Open 0.01 in., in. Hg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.5	2.5	2.0	-	-	-
Flow at 6-in. Hg, lb/min	0.73	0.73	0.73	0.65	0.65	0.65	0.68	0.68	0.68	0.68	0.68	0.68	-	-	-
Fuel Economy, mpg															
City	20	18	16	21	19	17	19.6[f]	18.9[f]	20[f]	24.6[f]	20[f]	5.1[f]	-	-	-
Highway	29	25	22	33	31	28	-	-	-	-	-	-	-	-	-
Exhaust Emissions, g/m															
HC	0.4	0.2	0.7	0.5	0.7	0.8	1.8[f]	1.6[f]	1.6[f]	2.1[f]	2.8[f]	2.6[f]	-	-	-
CO	6.8	6.6	7.4	4.9	8.3	8.3	26[f]	15[f]	18[f]	24[f]	24[f]	26[f]	-	-	-
NO_x	1.5	1.7	1.7	1.7	1.9	1.6	2.2[f]	2.2[f]	1.8[f]	1.8[f]	2.1[f]	1.3[f]	-	-	-

[a] Vega

[b] Monza

[c] Fuel economy and emissions represent averages of two emission data vehicles with identical calibration specifications.

[d] Calibrated to meet California emission standards.

[e] At 0.4-lb/min air flow.

[f] 1972 FTP

The air/fuel ratio modifications noted have been implemented by GM, in conjunction with other calibration changes, to meet the emission standards with acceptable fuel economy and driveability.

The GM air/fuel ratio calibration tolerance band is about ±4 percent and has not changed during the past several years.

4.4.3.4 Ignition System

4.4.3.4.1 Design Features

In 1975, GM introduced its breakerless high energy ignition (HEI) system on the 140-CID engine. The system includes a magnetic-pulse distributor featuring integrated electronics and a separate high energy ignition coil. The distributor consists of a pickup coil, a permanent magnet and pole piece with internal teeth located on the distributor shaft upper bushing, an electronic module, a condensor, a vacuum advance unit, and a timer core with external teeth attached to the centrifugal advance weight base. The condensor is used only for radio noise suppression.

Ignition voltage is generated in the coil secondary winding when the primary circuit is opened by the electronic module. The input signal to the module, which determines the time at which the module opens the primary circuit, is provided by a voltage induced in the pickup coil. The pickup coil voltage is, in turn, provided by alignment of the rotating timer core teeth with teeth of the stationary pole piece. A decrease in pickup coil voltage, at the instant the timer coil teeth pass the point of maximum inductance with the pole piece teeth, provides the required signal to the electronic module.

Ignition advance is provided by the centrifugal advance unit, which rotates the timer core relative to the distributor shaft, and the vacuum advance unit which rotates the pickup coil. Dwell period in terms of crankshaft degrees is automatically increased by the electronic control unit as engine speed increases. The system's output voltage to the spark plugs is in the 33-35 kV range with a rise time of 120 μsec.

In model years prior to 1975, a conventional breaker-point ignition system was used with the 140-CID engine.

4.4.3.4.2 Spark Timing Control Devices

On the model years of interest, carburetor ported vacuum and TCS advance is used as indicated in Table 4-31. Carburetor ported vacuum is obtained from a tap in the carburetor, located slightly above the closed position of the throttle plate. This arrangement provides the distributor with a non-zero vacuum advance signal only on opening of the throttle and sets vacuum advance at zero for closed throttle conditions. All model year 140-CID engines in Table 4-31 use carburetor ported vacuum.

For those models using TCS, carburetor ported vacuum is used but is defeated by a solenoid-operated valve when the vehicle operates in certain low forward transmission gears. For three speed manual transmission vehicles, vacuum advance is allowed only in third gear. Four speed manual units activate vacuum advance in the top two gears in 1972 but only in the top gear in 1974 and later model years. TCS when used with automatic transmissions is generally activated only in high gear, with one exception discussed below.

Vehicles using TCS also use a temperature override system which activates ported vacuum advance in all forward speeds for cold temperature operation. Cold override of TCS generally occurs for engine coolant temperatures below approximately 93 ±7°F. However, in 1976, override occurs below 140 ±5°F. System hysteresis is nominally 15°F.

For 1972 automatic transmission vehicles sold in California, ported vacuum advance is defeated in all transmission gears, and control is entirely dependent on the cold override switch. Exclusive cold override control of vacuum advance on these units is for NO_x abatement as only California mandated NO_x control standards in 1972.

A thermal check and delay valve is used on all 1975 and 1976 California 140-CID engines and on 1975 49-states engines supplied with two-venturi carburetors. The valve is sensitive to engine radiant heat and is designed to provide full carburetor ported vacuum to the distributor when sensed engine temperature is below 50°F. Above 50°F, the valve is in a restricting position which meters increasing carburetor ported vacuum signals to the distributor via a restricting orifice which delays vacuum advance by 10-15 seconds. Decreasing vacuum signals cause the valve to open so that the lower vacuum advance (retard) signal is immediately communicated to the distributor. Hysteresis of the system is effectively zero. The device is basically part of the NO_x control system of the 140-CID engine family.

4.4.3.4.3 Spark Advance Schedules

Typical spark advance schedules, exemplified by the 1976 California two-venturi carburetor configurations with automatic transmission, are presented in Figure 4-56, showing centrifugal and vacuum advance as a function of engine speed and applied vacuum. As indicated, the tolerance band, which has remained nearly constant over the past several years, is about ±2 deg for the centrifugal advance. The tolerance band of the vacuum advance varies between about ±4 deg at low vacuum levels and about ±1.5 deg at high vacuum.

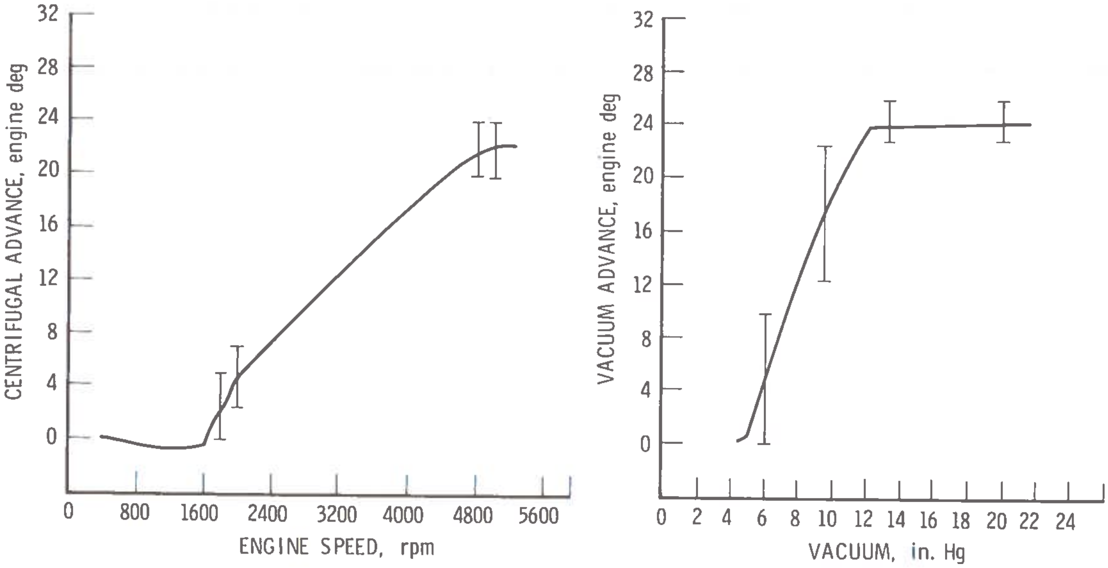


FIGURE 4-56. SPARK ADVANCE SCHEDULE: 1976 GM 140-CID ENGINE

The basic timing and the centrifugal and vacuum advance used by GM in 1972 and 1974-1976 is listed in Table 4-34 at discrete engine speed and vacuum settings. The centrifugal advance has increased between 1972 and 1974, showing no further change through 1976. Conversely, the vacuum advance has remained constant between 1972 and 1974, followed by a substantial rise in 1975, except for the low load regime, which shows nearly constant spark advance since 1972.

4.4.3.5 Exhaust Gas Recirculation

4.4.3.5.1 Design Features

EGR is used to aid in the control of NO_x on the 1974-1976 GM 140-CID engines described in Table 4-31. The system employed is modulated by carburetor ported vacuum obtained from a tap located just above the closed position of the carburetor throttle blade. In this system, the amount of exhaust gas admitted to the intake manifold is controlled by a valve responding to the ported vacuum signal. Thus, with the throttle blade closed, such as when the engine is at idle, there is no vacuum supplied to the EGR valve, and no exhaust gas is recirculated. However, when the throttle is partially opened, as during cruise or acceleration, the carburetor EGR port is uncovered by the throttle blade and subjected to a partial vacuum causing exhaust gas to be recirculated by the EGR valve. At WOT, there is little vacuum created at the EGR port, and little or no exhaust gas is recirculated. For the GM 140-CID engine, on-off temperature modulation of EGR by engine coolant is not used, and EGR is controlled only by the carburetor ported vacuum signal.

4.4.3.5.2 EGR Valve Calibration

Typical EGR valve calibration curves for the 49-states and California vehicles are presented in Figure 4-57, showing the air flow through the valve as a function of the applied signal vacuum. In both cases, a signal vacuum of about 2-in. Hg is required to open the valves. As the vacuum increases, the flow through the valves increases until the saturation flow level is reached. While the maximum flow rates are the same for the two valves, the California configuration is saturated much more rapidly. This is accomplished by varying the shape of the EGR valve pintle.

The calibration data of the certification vehicles considered in this study are listed in Table 4-34, showing the valve opening pressure and the maximum flow rate. While these data are not sufficient to characterize the operation of the EGR system over the Federal Driving Cycle, they permit

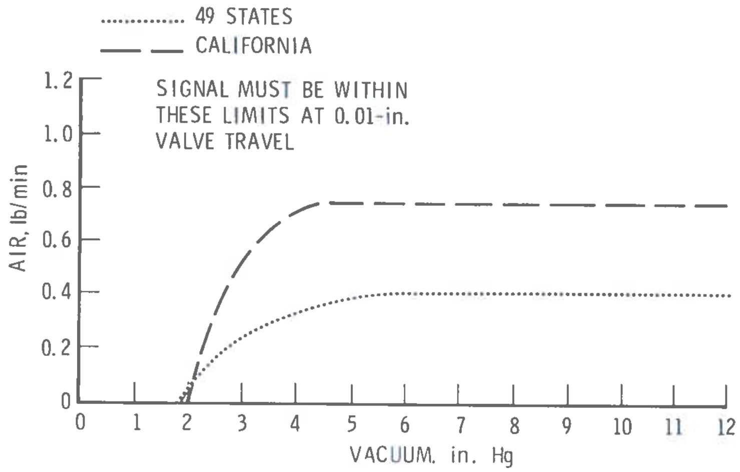


FIGURE 4-57. EGR VALVE FLOW CURVE: 1976 GM 140-CID ENGINE

qualitative conclusions to be drawn regarding the relative amount of EGR used in specific installations.

4.4.3.6 Secondary Air Injection

The 140-CID engine family uses the GM air injection reactor system (GMAIRS) on the models and in the model years as indicated in Table 4-31. The system is conventional, consisting of an engine-driven air pump, air manifold, diverter valve, check valve, and pressure relief valve. The pump is belt-driven and provides a continuous supply of compressed air to the air manifold for injection into an area near each engine exhaust valve.

The diverter valve diverts air to the atmosphere during vehicle deceleration to prevent engine backfire that could result from mixing fresh air and fuel-rich exhaust gases associated with vehicle deceleration. The pressure relief valve is incorporated as part of the diverter valve assembly and provides an atmospheric discharge for the system at high engine speeds to prevent excessively high exhaust system temperatures. The check valve is provided in the system to prevent exhaust gas backflow into the air pump and possible pump damage.

Air pump flow rate is set at 33 lb/hr minimum at 1000-pump rpm against a backpressure of 1.6-in. Hg. Flow rate is essentially linear with engine speed for the positive displacement pump, and air flow rate is set on a particular engine family by selection of the pump pulley size. The pulley ratio is 1.15 for the 140-CID engine and acts in a manner to increase pump speed relative to engine speed.

4.4.3.7 Catalytic Converter

Some versions of the 140-CID engine employ an oxidizing catalytic converter for the 1975/1976 model year (Table 4-34). The active catalytic material is 71 percent platinum and 29 percent palladium, deposited on alumina pellets and located in an underfloor container of 160-cu in. for 49-states vehicles. Cars sold in California use a 260-cu in. converter because of the more restrictive California HC and CO emissions standards. No vehicle or catalyst protection or warning systems are used.

4.4.3.8 Crankcase and Evaporation Emission Control System

The GM crankcase emission control system used on the 140-CID engine family is of the closed type.

The GM evaporative emission control system (GMECS) uses a staged canister purge system consisting of a sealed fuel tank, a fill limiter to provide fuel tank expansion volume, and a canister containing activated carbon for storage of fuel vapor.

Both systems are functionally similar to the respective systems described in Section 3.

4.4.3.9 Fuel Economy and Emissions

The fuel economy and emission data for selected 1974-1976 certification vehicles with automatic and manual transmissions are listed in Table 4-34 (Refs. 4-15 through 4-20). The city fuel economy of these vehicles and the fuel economy data obtained from the EPA for a number of additonal certification vehicles (Refs. 4-75) have been normalized, using the method described in Section 3.3 and have been averaged at the various calibration levels shown in Figures 4-58 and 4-59. Also shown in these figures are the normalized average fuel economy of the 1973 certification vehicles (Ref. 4-21) and a number of 1971 and 1972 in-use vehicles (Refs. 4-37 through 4-34).

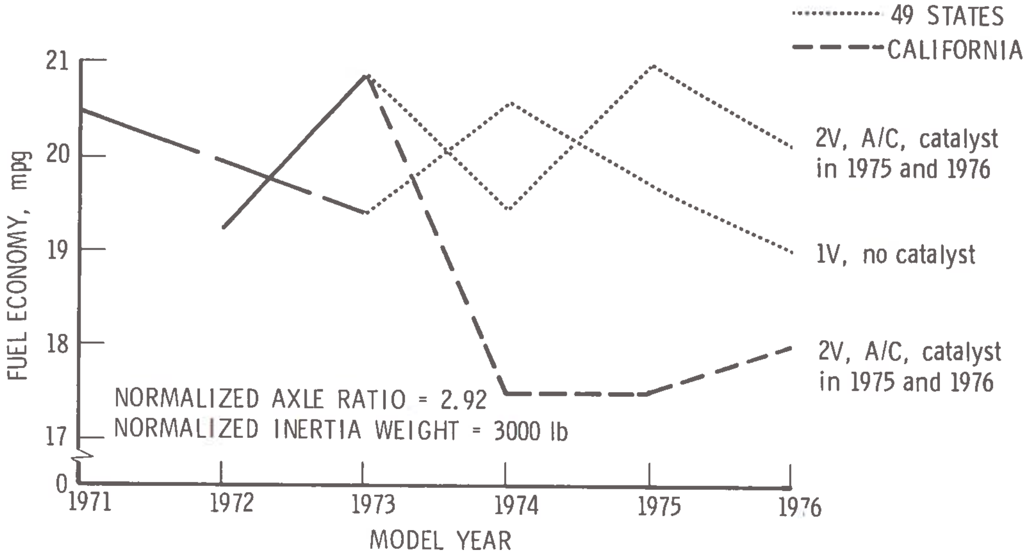


FIGURE 4-58. NORMALIZED AVERAGE CITY FUEL ECONOMY: GM 140-CID ENGINE WITH AUTOMATIC TRANSMISSION

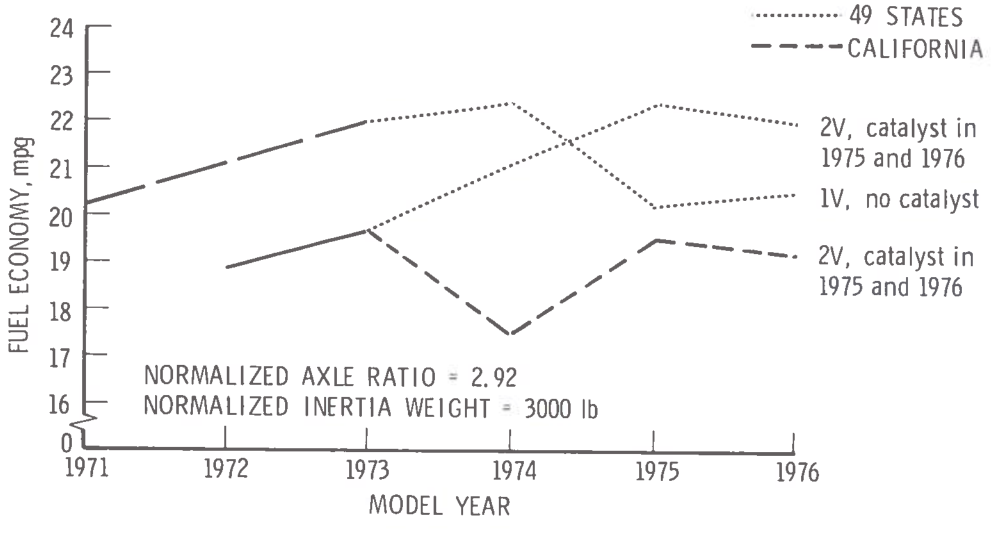


FIGURE 4-59. NORMALIZED AVERAGE CITY FUEL ECONOMY: GM 140-CID ENGINE WITH MANUAL TRANSMISSION

Since the rear axle ratio of the in-use vehicles had not been specified, the normalization of the data has been limited to the inertia weight.

As seen in Figure 4-58, the fuel economy of the 49-states vehicle with automatic transmission, A/C, and a two-venturi carburetor shows only small variations over the 1973-1975 time period. This is consistent with the nearly constant carburetor, distributor, and EGR valve settings used with these vehicles and shown in Table 4-34. The substantial reduction of the HC and CO emissions obtained in 1975 is attributed entirely to the use of an oxidation catalyst in these vehicles. Fuel economy variations of non-catalyst single-venturi vehicles shown in Figure 4-58 exhibit similar small excursions. As with the two-venturi vehicles, engine component calibrations have remained nearly constant between 1973 and 1976, while emissions have declined. On the basis of available calibration information, the emission reduction realized in 1975 is difficult to rationalize.

The California fuel economy curve for automatic transmission vehicles with A/C shows a decline from 1973 to 1974, which is attributed to the imposition of a lowered NO_x emission standard in 1974. The small fuel economy variations from 1974 to 1976 are attributed to vehicle-to-vehicle and test-to-test variabilities and potential inaccuracies in the normalization procedure. In general, the fuel economy of vehicles without A/C is slightly higher than air conditioned vehicles. Again, emission reductions observed in Table 4-34 are a result of catalyst usage in 1975 and 1976.

The fuel economy of the manual transmission, non-catalyst vehicles with single-venturi carburetor and without A/C shown in Figure 4-59 is constant between 1973 and 1974. This is as expected because the 49-states emission standards remained unchanged between 1973 and 1974. The substantial drop in fuel economy is attributed to the use of TCS in 1975 on the subject engines. As explained in Section 4.4.3.4, TCS deactivates vacuum ignition advance over much of the Federal Driving Cycle. The subsequent small rise in fuel economy from 1975 to 1976 is attributed to test variabilities. The lower 1975 and 1976 HC and CO emission standards were met by means of TCS and the use of secondary air injection. Although the vehicle data with A/C is limited it appears that a small fuel economy penalty is incurred as a result of A/C.

The 1974 drop in the fuel economy of the two-venturi carburetor California vehicles with manual transmission and no A/C is a result of the more stringent 1974 California NO_x standard relative to the 1973 standard. The subsequent improvement in fuel economy in 1975 reflects the deletion of TCS, which was used in 1974. This was made possible by the use of an oxidation catalyst in 1975. As engine component calibration settings remain constant between 1975 and 1976, the small decline in fuel economy observed in 1976 is explained as normal test variations. The fuel economy of A/C vehicles is approximately 6 percent lower than for non-A/C vehicles.

4.4.4 GM 250-CID Engine

4.4.4.1 Engine Modifications

Significant recent changes in the 250-CID engine combustion chamber design have been brought about by the 1975 addition of early fuel evaporation (EFE) to some 250-CID engines. This has resulted in the concurrent availability of two different versions of the Chevrolet 6-cylinder powerplant. The newer of the two versions, designated "No. 1" in Table 4-32, has an integral cylinder head-intake manifold configuration incorporating passageways which implement EFE. For cold engine operating conditions, the passageways, in conjunction with an open engine oil temperature modulated EFE valve, route hot exhaust gases past the base of the carburetor. The resulting rapid carburetor warmup improves fuel vaporization and decreases HC emissions. Above sensed engine oil temperatures of $150^{\circ}F$, the EFE valve closes, and exhaust gases are passed directly to the exhaust system.

The engine designated "No. 2" in Table 4-32 uses a conventional bolt-on intake manifold and does not incorporate EFE. It is apparently being phased out of production in favor of the new integral cylinder head-intake manifold design as it is used only in limited quantities on 49-states automatic transmissions vehicles. In California the integral design has been used exclusively since the beginning of the 1975 model year.

Changes in combustion chamber design parameters associated with the change to EFE are shown in Table 4-32. As may be seen, the engine surface-to-volume ratio, compression ratio, and valve timing have been altered. Valve timing, in particular, shows a rather marked increase in valve overlap for the EFE configuration. These modifications have been implemented as part of the GM overall approach to meeting the increasingly stringent emission regulations, consistent with acceptable fuel economy and driveability.

4.4.4.2 Intake System

Thermostatic control of carburetor intake air is used on the 1976 250-CID engine and on earlier year engines as indicated in Table 4.32. The system is functionally the same as described in Section 4.4.3.2.

4.4.4.3 Carburetor

4.4.4.3.1 Design Features

A single-venturi carburetor has been used on all models of the GM 250-CID engine since 1968. In all years, a stepped metering rod enrichment system has been employed, and, in addition, a carburetor using a power valve form of enrichment was offered in 1968.

Modern versions of the carburetor used on the 250-CID engine use a conventional float and idle system. The idle system is of the bypass type and uses a slotted off-idle port for low-speed, part-throttle operations.

Main metering is accomplished by throttle linkage actuating a metering rod in a fixed orifice with double boost venturi's used to obtain sensitive fuel metering over a wide range of engine loads. The metering rod is also controlled by intake manifold vacuum to provide power enrichment as a function of engine load. A conventional acceleration pump system is used to provide good low-speed acceleration.

A fully automatic choke implemented with a bimetallic thermostatic coil sensitive to exhaust manifold heat is utilized in conjunction with a vacuum diaphragm actuated primary break. The primary vacuum break provides an initial choke valve opening sufficient to keep the engine running after a cold start. An auxiliary vacuum break unit or secondary choke pulloff is also used. This system is controlled by engine coolant temperature. For coolant temperatures above 80°F, intake manifold vacuum is supplied to the diaphragm of the auxiliary break unit, which pulls the choke valve to a nearly full-open position. Hysteresis is approximately 10°F.

Electric assist is not used; however, a bimetallic hot idle compensator is supplied which opens a valve to provide 0.19-lb/min additional air beneath the throttle plate during hot idle operation for carburetor temperatures above 200°F. Dieseling after ignition shutoff is prevented by an idle stop solenoid.

4.4.4.3.2 Air/Fuel Ratio Versus Load

The air/fuel ratio settings used in the 1974 through 1976 model year are presented in Table 4-35. The most notable characteristic is the dichotomy between EFE and non-EFE equipped engines. Leaner air/fuel ratios associated with EFE usage are a result of the improved vaporization characteristics during engine warmup.

4.4.4.4 Ignition System

4.4.4.4.1 Design Features

The design of the ignition system for the GM 250-CID engine is essentially the same as that described in Section 4.4.3.4.1. A conventional breaker-point system is used in all pre-1975 models, whereas the new breakerless configuration has been used since 1975.

The ignition advance system described previously for the 140-CID engine is generally applicable to the 250-CID engine except that the thermal check and delay valve is not used. Also, on 1975 and 1976 49-states engines intake manifold vacuum is used rather than ported vacuum as the signal source. California units retain ported vacuum, which is universally used in conjunction with TCS in 1974 as indicated in Table 4-32. The TCS time delay, listed as an auxiliary device in the table, delays the use of TCS for approximately 20 second
after the ignition is turned on.

4.4.4.4.2 Spark Advance Schedules

The centrifugal and vacuum advance schedules of the 1967-1976 model 49-states and California vehicles with manual and automatic transmission are listed in Table 4-35. As an aid in the discussion of ignition timing modifications incorporated by GM over the past several years, Figures 4-60 and 4-61 have been prepared. These figures show the centrifugal and vacuum advance of the 49-states vehicles without EFE as a function of engine speed and applied vacuum. As may be seen in Figure 4-60, a decline from 1967 to 1972 is evident and is attributed to increasingly stringent HC and CO standards implemented over the subject time period. Subsequently, the spark timing has been

TABLE 4-35. CERTIFICATION CALIBRATION DATA: GM 250-CID ENGINE

Engine / Vehicle Parameter	Model Year and Certification Standard																					
	1976 49 States					1976 California		1975 49 States					1975 Calif	1974 49 States						1970		1967
Vehicle Model	N[a]	N[a]	N[a]	Ma[b]	Ma[b]	MN[c, d]	Ca[e]	N[a]	Ma[b]	N[a]	N[a]	N[a]	N[a]	N[a]	N[a]	C[f]	C[f, g]	G[h]	P[i]	-	-	-
Transmission Type	A3	A3	A3	A3	M3	A3	A3	A3	M3	A3	A3	A3	A3	A3	A3	M3	M3	A3	M4	A	M	A/M
Vehicle Inertia Weight, lb	3500	3500	4000	4500	4000	4000	4000	4000	4000	4000	4000	4000	4000	3500	4000	4000	4000	4500	4500	-	-	-
Rear Axle Ratio	2.73	3.08	2.73	3.08	2.73	2.73	3.08	2.73	3.08	3.08	2.73	3.08	3.08	3.08	3.08	3.73	4.11	4.11	4.11	-	-	-
Catalyst	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
No. of Carburetor Venturi's	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	-	-
Carburetor Calibration, A / F																						
Idle: 1.0 lb / min air flow	13.1	13.2	13.2	13.3	15.8	12.7	12.7	13.2	16.0	13.2	13.5	13.5	12.4	13.0	13.0	10.5	10.5	13.0	10.5	-	-	-
Off Idle: 2.0 lb / min air flow	14.8	15.8	15.8	15.9	16.8	15.1	15.1	15.4	17.1	15.4	14.8	14.8	15.0	14.2	14.2	13.2	13.2	14.2	13.2	-	-	-
Part Throttle: 4.0 lb / min air flow	15.9	18.0	18.0	18.3	17.2	17.3	17.3	17.8	17.7	17.8	15.7	15.7	17.1	14.9	14.9	13.7	13.7	14.9	13.7	-	-	-
WOT at Max.: 12.0 lb / min air flow	11.8	12.0	12.0	12.2	11.9	11.9	11.9	11.7	11.5	11.7	12.2	12.2	11.9	11.4	11.4	11.5	11.5	11.4	11.5	-	-	-
Basic Timing, crankshaft deg BTC	8	10	10	10	6	10	10	10	10	10	8	8	10	8	8	8	8	8	8	4	0	4
Centrifugal Advance, crankshaft deg																						
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.0	2.0
1500 rpm	5.0	2.0	2.0	2.0	6.0	2.0	2.0	2.0	2.0	2.0	4.5	4.5	2.0	4.5	4.5	4.5	4.5	4.5	4.5	10.0	15.0	14.0
2000 rpm	10.5	5.0	5.0	5.0	8.0	5.0	5.0	5.0	5.0	5.0	10.5	10.5	5.0	10.5	10.5	10.5	10.5	10.5	10.5	17.0	21.0	19.0
3000 rpm	18.0	10.5	10.5	10.5	14.0	10.5	10.5	10.0	10.0	10.0	18.0	18.0	10.0	18.0	18.0	18.0	18.0	18.0	18.0	22.0	26.0	30.0
4000 rpm	24.0	16.0	16.0	16.0	19.0	16.0	16.0	15.0	15.0	15.0	23.5	23.5	15.0	23.5	23.5	23.5	23.5	23.5	23.5	27.0	31.0	-
5000 rpm	24.0	16.0	16.0	16.0	19.5	16.0	16.0	16.0	16.0	16.0	24.0	24.0	16.0	24.0	24.0	24.0	24.0	24.0	24.0	-	-	-
Vacuum Advance, crankshaft deg																						
5 in. Hg	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 in. Hg	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 in. Hg	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	4.0	4.0	8.0	4.0	4.0	4.0	4.0	4.0	4.0	2.0	2.0	5.0
10 in. Hg	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	11.0	11.0	12.0	11.0	11.0	11.0	11.0	11.0	11.0	8.0	8.0	10.0
12 in. Hg	17.0	17.0	17.0	17.0	19.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	15.0	17.0	17.0	17.0	17.0	17.0	17.0	10.0	10.0	12.0
15 in. Hg	18.0	18.0	18.0	18.0	23.0	18.0	18.0	18.0	18.0	18.0	23.0	23.0	15.0	23.0	23.0	23.0	23.0	23.0	23.0	20.0	20.0	21.0
20 in. Hg	18.0	18.0	18.0	18.0	24.0	18.0	18.0	18.0	18.0	18.0	24.0	24.0	15.0	24.0	24.0	24.0	24.0	24.0	24.0	23.0	23.0	21.0
EGR Valve Calibration																						
Signal Pressure To Open, in. Hg	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	-	-	-
Flow at 6-in. Hg, cfm	0.36	0.3	0.3	0.46	0.30	0.83	0.83	0.46	0.38	0.46	0.37	0.37	0.83	0.67	0.67	0.56	0.96	0.75	0.56	-	-	-
Fuel Economy, mpg																						
City	18	18	17	16	18	15	16	16	15	16	-	-	15	15.2[j]	15.7[j]	13.5[j]	11.7[j]	12.4[j]	9.4[j]	-	-	-
Highway	24	24	23	19	26	21	20	22	23	20	-	-	20	-	-	-	-	-	-	-	-	-
Exhaust Emission, g / m																						
HC	1.3	0.6	0.5	1.0	1.1	0.6	0.5	0.7	0.7	0.8	1.0	1.0	0.5	-	-	-	-	-	-	-	-	-
CO	8	4	4	7	6	4	3.5	7	10	6	4	6	8.3	-	-	-	-	-	-	-	-	-
NO_x	2.7	2.4	2.9	2.6	2.8	1.9	1.5	2.1	1.9	2.1	2.7	2.6	1.4	-	-	-	-	-	-	-	-	-

[a] Nova

[b] Malibu

[c] Malibu; Nova

[d] Fuel economy and emissions represent averages of two emission data vehicles with identical calibration specifications.

[e] Camaro

[f] C10 van

[g] Calibrated to meet California emission standards.

[h] G20 van

[i] P10 van

[j] 1972 FTP

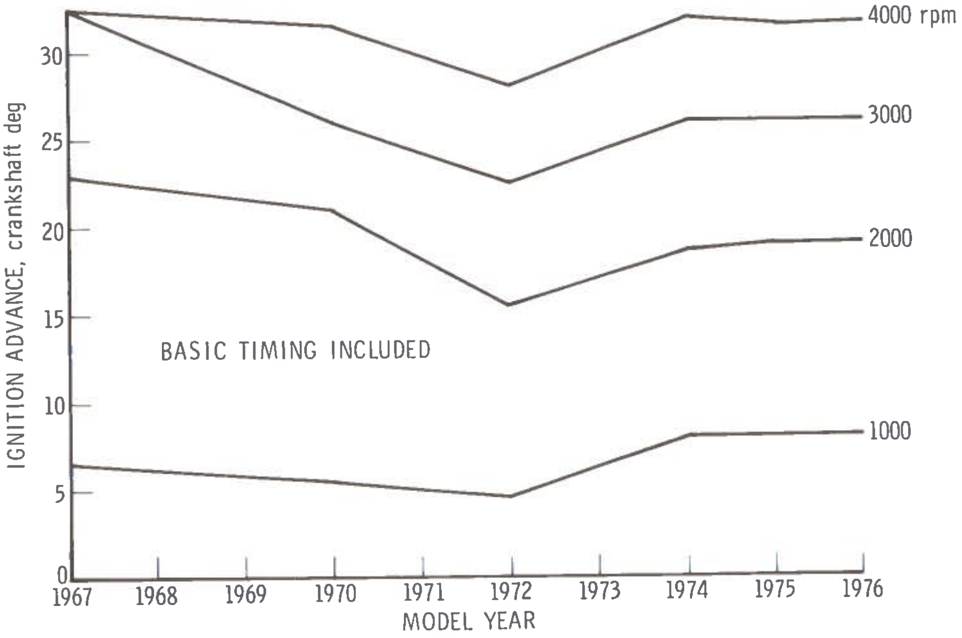


FIGURE 4-60. CENTRIFUGAL SPARK ADVANCE SCHEDULE: GM 250-CID ENGINE WITH AUTOMATIC TRANSMISSION; NO EFE; 49-STATES CALIBRATION

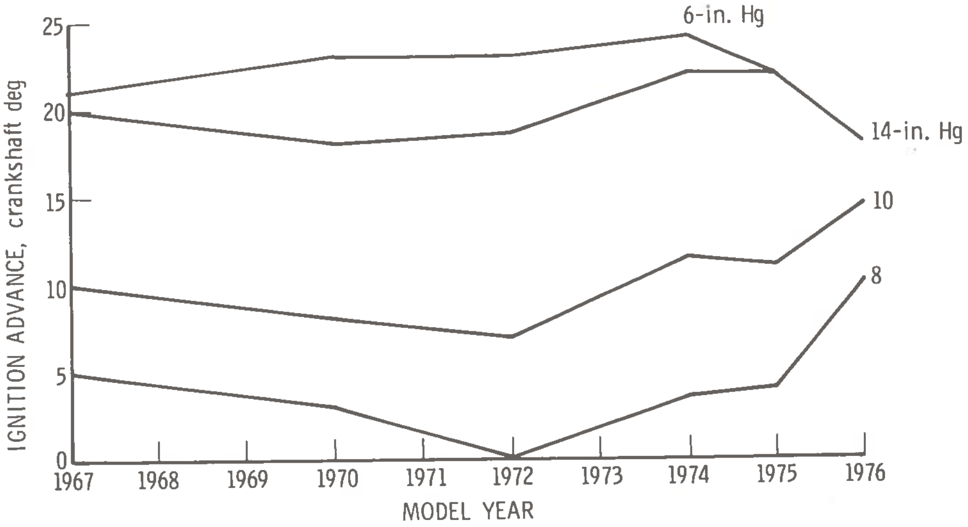


FIGURE 4-61. VACUUM SPARK ADVANCE SCHEDULE: GM 250-CID ENGINE WITH AUTOMATIC TRANSMISSION; NO EFE; 49-STATES CALIBRATION

advanced, particularly in the low-speed regime. This is indicative of a shift in the NO_x control burden from the ignition system to the EGR system and, more recently, a shift from use of ignition retardation to use of an oxidizing catalyst as a primary HC and CO emission control method. While HC and CO emission standards become more strict in 1975, centrifugal advance remains unchanged between 1974 and 1976 because the additional emission control burden is shifted from the engine to the catalyst. Similar trends are observed for the manual transmission equipped vehicles.

The vacuum advance shown in Figure 4-61 duplicates the trend of the centrifugal advance through 1975, and is followed by a moderate increase of the advance at medium engine loads and a small decline at low loads in 1976.

4.4.4.5 Exhaust Gas Recirculation

4.4.4.5.1 Design Features

The EGR system of the GM 250-CID engine is functionally the same as the system used with the 140-CID engine described in Section 4.4.3.5, with one exception: For the 250-CID engine family, on-off engine coolant temperature modulation of EGR is used. The system is implemented by a coolant temperature-actuated thermal vacuum switch which disables the EGR system by interrupting the vacuum to the EGR valve for coolant temperatures below 100°F. The hysteresis band of the system is 13°F or less. Coolant temperature modulation of EGR is used to improve driveability during engine warmup when engine temperatures are relatively low and the generation of NO_x is not a critical problem.

4.4.4.5.2 EGR Valve Calibration

The EGR calibration data, presented in Table 4-35, show the signal vacuum required to open the valve and the maximum valve flow rate. The flow characteristics of the valve are similar to those shown in Figure 4-57 for the 140-CID engine. Generally, declining EGR flow rates from 1974-1976 49-states vehicles indicate the use of increasingly efficient EGR systems, supplying EGR at the critical load conditions of the Federal Driving Cycle. As expected, EGR flow rates for California vehicles are substantially higher than the 49-states configurations and have remained nearly constant for the past three model years.

4.4.4.6 Secondary Air Injection

As indicated in Table 4-32, secondary air injection has been widely used in early model years but more recently is limited to California applications. The system is functionally identical to the one described in Section 4.4.3.6 for the 140-CID engine. The pump pulley ratio is 1.15 to 1 for the 250-CID engine.

4.4.4.7 Catalytic Converter

A catalytic converter with a volume of 260 cu in. is used on both the Federal and California versions of the GM 250-CID engine. The catalyst loading and system design are similar to the configuration described in Section 4.4.3.7.

4.4.4.8 Crankcase and Evaporative Control Systems

The crankcase and evaporative emission control systems are similar to the systems described in Section 3.

4.4.4.9 Fuel Economy and Emissions

City and highway fuel economy and emission data for the 1973-1976 certification vehicles are presented in Table 4-35 (Refs. 4-15 through 4-21). Following the previously described procedure, the fuel economy of the 1973 and 1974 vehicles have been increased by 5 percent to account for the differences in the 1972 and 1975 FTP, and all data have been normalized to a common inertia weight of 4000 pounds and rear axle ratio of 2.73. As indicated in Figure 4-62, the normalized average fuel economy of the 49-states vehicles with automatic transmission rises sharply between 1973 and 1974. This is difficult to explain because the emission standards remain unchanged for these two model years. While no engine calibration data are available for 1973, it is conceivable that GM has shifted the burden of NO_x control from spark retard to EGR in 1974. The subsequent small reduction in the average fuel economy in 1975 might be attributed to the slightly lower centrifugal and vacuum spark advance used in 1975 in the engine speed and load regime of the Federal Driving Cycle. In view of the nearly identical distributor settings used in 1975 and 1976 and the slightly lower maximum EGR valve flow rates

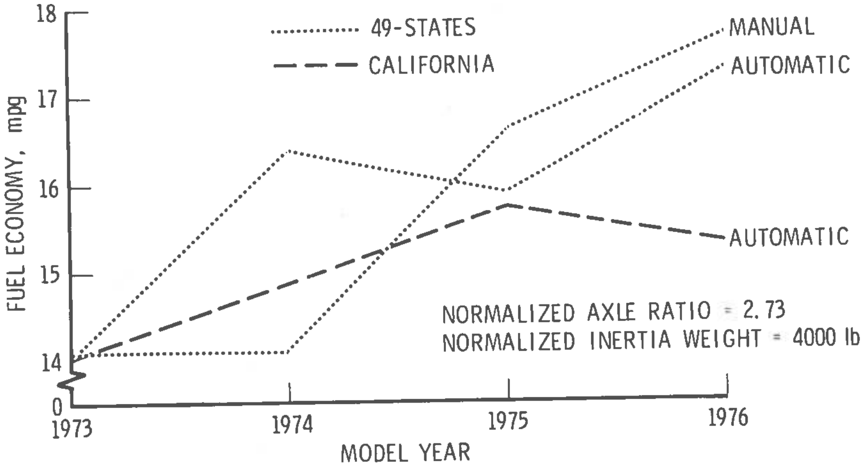


FIGURE 4-62. NORMALIZED AVERAGE CITY FUEL ECONOMY: GM 250-CID ENGINE

of the 1976 calibration, the observed fuel economy increase in 1976 can not be rationalized on the basis of the information currently available for this engine.

While the rise in fuel economy of the 49-states vehicles in 1975 is attributed to the deletion of TCS in 1975 and the attendant gain in vacuum advance, the additional increase observed for these vehicles in 1976 can not be explained at this time.

As shown in Table 4-35, the HC emission of the EFE-equipped vehicles are considerably lower than for the vehicles without EFE, reflecting the improved fuel vaporization characteristics realized with EFE.

In general, the fuel economy of the California vehicles is lower than for the corresponding 49-states vehicles, reflecting the higher EGR flow rates used in the California vehicles to meet the more stringent California NO_x standard.

4.4.5 GM 350-CID Engine

4.4.5.1 Engine Modifications

An overview of the Chevrolet version of the GM 350-CID engine is given in Table 4-33. As indicated, the subject engine uses a wedge type of combustion chamber and has a surface area to volume ratio of 6.27/inch. Also, as shown in the table, compression ratios have been considerably lowered over the years as a result of the imposition of NO_x emission standards and the requirement of satisfactory engine operation on 91 octane gasoline.

The valve overlap of the 49-states engines has remained constant for the past three model years. Conversely, the high valve overlap used on the 1974 California engines was reduced to the 49-states level in 1975. As discussed in Section 4.4.5.9, this change has contributed to the fuel economy improvement realized in 1975. Since the California NO_x standard does not change between 1974 and 1975, the relaxation of valve overlap in 1975 suggests that the large overlap in 1974 might have been used primarily for HC rather than NO_x abatement. This is further supported by the fact that catalytic converters, introduced in 1975, provide an opportunity to shift the HC and CO emission control burden from the engine to the converter.

4.4.5.2 Intake System

The 350-CID engine family currently uses a thermostatically controlled air cleaner which is functionally the same as the unit described in Section 4.4.3.2. Also, the EFE system of this engine is similar to that used in the 250-CID engine, except that the system is controlled by coolant temperature rather than engine oil temperature. The actuation temperature is 180 $\pm 3^{\circ}F$ with approximately $10^{\circ}F$ of hysteresis.

4.4.5.3 Carburetor

4.4.5.3.1 Design Features

The 350-CID engine is offered with either a two- or four-venturi carburetor in 49-states vehicles and, since 1974, only with a four-venturi unit in California.

The float systems on both two- and four-venturi carburetors are conventional needle valve units. The idle systems are also conventional and similar, with idle air bleeds used to prepare an air/fuel mixture which is discharged below the throttle blade. On the four-venturi carburetor only the primary side is equipped with an idle system, and some four-venturi units have a fixed idle air bypass system consisting of air channels leading from the top of each primary carburetor bore to a point below each primary throttle blade. At normal idle, extra air passes through these channels, supplementing the air passing by the slightly opened primary throttle blades. The purpose of the idle bypass system is to allow a reduction of the air flow past the throttle blades at idle. This reduces the amount of air flowing through the venturi and prevents fuel flow in the main nozzles during idle operation. A conventional off-idle discharge port is used for initial part-throttle operation in both the two- and four-venturi carburetors. Idle limiter caps are used; however, an idle stop device is not fitted.

The main metering system of the two-venturi carburetors is of conventional fixed orifice design, employing air bleeds and a boost venturi for mixture control. An additional fuel circuit is used to supplement the main metering system by providing additional fuel under part-throttle, high air flow operation. Enrichment is implemented by calibrated ports located in the air horn above the choke valve. These ports feed fuel from the float bowl only at high carburetor air flow rates.

Main metering in the four-venturi carburetor is provided by boost venturi's working in conjunction with metering rods. For the 1975 model year, California units are equipped with altitude compensation in the form of an aneroid bellows, which is an integral part of each primary metering rod assembly. However, this feature has been dropped for 1976. The primary venturi's are also equipped with a part throttle supplemental fuel enrichment system similar to the two-venturi system described previously.

A conventional vacuum-operated power valve is used with the two-venturi carburetor to obtain enrichment under heavy load conditions. The four-venturi unit uses a vacuum control of the primary metering rods to obtain the required enrichment. Also, as engine speed increases, flow through the secondary bores creates a vacuum which operates an air valve and cam mechanism, causing the secondary metering rods to withdraw from the secondary orifices and provide fuel flow proportional to air flow.

Acceleration systems are similar on both the two- and four-venturi carburetors. A conventional vacuum and spring operated pump is used to maintain proper air/fuel ratios during rapid throttle openings at low speed.

Chokes on both carburetors are operated by thermostatic bimetallic coils with an initial vacuum break system used to open the choke valve to a point at which the engine will run without stalling. A secondary choke pulloff is not used. On the four-venturi unit, choke action is associated only with primary venturi's, and secondary throttle valves are locked out by choke operation during engine warmup.

4.4.5.3.2 Carburetor Calibration

The available carburetor calibration data for the 350-CID engine are listed in Table 4-36 at four discrete air flow settings. On balance, the air/fuel ratio of the 49-states vehicles increase moderately between 1974 and 1975 and then hold nearly constant from 1975 to 1976 for vehicles with EFE. California vehicles in 1975 use considerably leaner ratios than in 1974 and then show somewhat richer settings for 1976. These trends are likely a result of the 1975 introduction of EFE and catalysts. The former promotes fuel vaporization, whereas both devices allow leaner carburetor settings while maintaining good cold engine operation and reduced HC emissions.

4.4.5.4 Ignition System

4.4.5.4.1 Design Features

The ignition system is similar to the one described in Section 4.4.3.4.1, except that the ignition coil is incorporated as an integral part of the distributor on the 1975 and 1976 350-CID engines instead of being a separate unit as described previously.

4.4.5.4.2 Ignition Advance

Figures 4-63 and 4-64 present the centrifugal and vacuum ignition advance schedules for automatic transmission equipped vehicles versus model year parametized on-engine speed and applied vacuum, respectively. As with the two GM engines discussed previously, TCS is used on some models, as indicated in Table 4-33. The system is essentially the same as the one described for the 140-CID engine, except that TCS modulates full intake manifold vacuum rather than ported vacuum. For those models listed as not using TCS, continuous ported vacuum advance is provided.

As seen in Figure 4-64, vacuum ignition advance exhibits some rather substantial increases between the 1970-1974 model years in the middle to heavy load regions. However, these years are the time period in which NO_x emission standards are phased in. Since TCS is one of the most used methods of initially coping with NO_x emissions, it should be noted that the

TABLE 4-36. CERTIFICATION CALIBRATION DATA: GM 350-CID ENGINE

Engine/Vehicle Parameter	Model Year and Certification Standard																											
	1976 49 States						1976 California			1975 49 States							1975 California			1974 49 States							1970	
Vehicle Model	Ma[a]	MC[b]	I[c]	Cc[d]	Ca[e]	Cc[d]	Ca[e]	Ma[a]	Cc[d]	I[c]	Ma[f]	Ca[e]	Ma[a]	N[g]	N[g]	Ca[e]	I[c]	N[g]	Ma[a]	K[h]	Ma[a]	I[c]	I[c]	G[i]	C[j, k]	C[j]	-	-
Transmission Type	A3	A3	A3	A3	A3	A3	A3	A3	A3	A3	A3	M3	A3	A3	M3	A3	A3	A3	A3	A3	A3	A3	A3	M3	A3	A3	A3	M3
Vehicle Inertia Weight, lb	4500	4500	5000	5000	4000	5000	4000	4500	5000	5000	5000	4000	4500	4000	4000	4000	5000	4000	4500	5000	4500	5000	4500	4500	4500	4500	-	-
Rear Axle Ratio	2.56	2.73	2.73	3.08	3.08	2.73	3.08	2.73	3.08	3.08	2.73	2.56	2.73	2.56	2.73	3.08	3.08	2.56	2.73	4.11	2.73	3.42	3.08	3.73	3.07	3.07	-	-
Catalyst	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No
No. of Carburetor Venturi's	2	2	2	2	4	4	4	4	4	2	2	2	2	2	2	4	4	4	4	2	2	2	2	2	4	4	-	-
Carburetor Calibration, A/F																												
Idle: 1.6-lb/min air flow (2V) 1.2-lb/min air flow (4V)	13.7	13.7	13.7	13.7	14.0	14.0	14.0	14.0	14.0	13.5	13.5	13.5	13.5	13.5	13.5	13.4	14.3	14.3	14.3	12[m]	12[m]	12[m]	12[m]	13.3	12[m]	12.4[m]	-	-
Off Idle: 2.5-lb/min air flow	13.8	13.8	13.8	13.8	16.1	16.1	16.2	16.2	16.2	13.8	13.8	13.8	13.8	13.8	13.8	16.9	17.1	17.1	17.1	13.1	13.1	13.1	13.1	14.0	12.4[n]	13.7[o]	-	-
Part Throttle: 5-lb/min air flow (2V) 6-lb/min air flow (4V)	15.7	15.7	15.7	15.7	16.5	16.5	16.3	16.3	16.3	15.3	15.3	15.3	15.3	15.3	15.3	17.0	17.0	17.0	17.0	15.3	15.3	15.3	15.3	15.2	15.4[p]	16.0[p]	-	-
WOT at Max.: 20-lb/min air flow (2V) 40-lb/min air flow (4V)	12.7	12.7	12.7	12.7	13.4	13.4	13.4	13.4	13.4	12.8	12.8	12.8	12.8	12.8	12.8	13.1	12.9	12.9	12.9	11.8	11.8	11.8	11.8	11.8	13.6	13.6	-	-
Basic Timing, crankshaft deg BTC	6	6	6	6	8	8	6	6	6	6	6	6	6	6	6	8	6	6	6	8	8	8	8	0	8	8	4	0
Centrifugal Advance, crankshaft deg																												
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0
1500 rpm	4.5	4.5	4.5	4.5	9.5	9.5	5.5	5.5	5.5	4.5	4.5	4.5	4.5	4.5	4.5	9.5	4.5	4.5	3.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	12.0	16.0
2000 rpm	12.0	12.0	12.0	12.0	14.0	14.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	14.0	12.0	12.0	8.0	6.5	6.5	6.5	6.5	6.5	7.5	7.5	16.0	20.5
3000 rpm	16.5	16.5	16.5	16.5	17.5	17.5	16.0	16.0	16.0	16.5	16.5	16.5	16.5	16.5	16.5	17.5	16.5	16.5	14.0	12.5	12.5	12.5	12.5	12.5	13.5	13.5	20.0	24.0
4000 rpm	21.0	21.0	21.0	21.0	20.5	20.5	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	20.5	21.0	21.0	18.5	19.0	19.0	19.0	19.0	19.0	17.0	17.0	23.5	28.0
5000 rpm	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	19.5	20.0	20.0	20.0	20.0	20.0	18.0	18.0	-	-
Vacuum Advance, crankshaft deg																												
5 in. Hg	2.5	2.5	2.5	2.5	2.5	2.5	0.0	0.0	0.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.0	6.0	6.0	6.0	6.0	6.0	0.0	0.0	0.0	0.0
6 in. Hg	5.0	5.0	5.0	5.0	5.0	5.0	1.0	1.0	1.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	0.0	9.0	9.0	9.0	9.0	9.0	0.0	0.0	0.0	0.0
8 in. Hg	9.5	9.5	9.5	9.5	9.5	9.5	6.0	6.0	6.0	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	5.0	13.0	13.0	13.0	13.0	13.0	4.5	4.5	0.0	0.0
10 in. Hg	14.0	14.0	14.0	14.0	14.0	14.0	10.5	10.5	10.5	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	10.0	14.0	14.0	14.0	14.0	14.0	8.5	8.5	0.0	0.0
12 in. Hg	17.5	17.5	17.5	17.5	17.5	17.5	14.0	14.0	14.0	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	14.0	14.0	14.0	14.0	14.0	14.0	12.0	12.0	6.0	4.0
15 in. Hg	17.5	17.5	17.5	17.5	17.5	17.5	15.0	15.0	15.0	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	15.0	14.0	14.0	14.0	14.0	14.0	15.0	15.0	14.0	12.0
20 in. Hg	17.5	17.5	17.5	17.5	17.5	17.5	15.0	15.0	15.0	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	15.0	14.0	14.0	14.0	14.0	14.0	15.0	15.0	20.0	15.0
EGR Valve Calibration																												
Signal Pressure To Open 0.01 in., in. Hg	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	-	-
Flow at 6-in. Hg, lb/min	0.5	0.5	0.5	0.5	0.5	0.5	0.38	0.5	0.55	0.5	0.5	0.28	0.5	0.38	0.28	0.3	0.94	0.38	0.5	0.66	0.66	0.66	0.66	0.5	0.66	0.5	-	-
Fuel Economy, mpg																												
City	14	13	13	13	14	13	13	13	11	13	12	14	13	14	12	-	11	14	12	9.6[f]	9.9[q]	11.6[q]	10.1[q]	8.5[q]	0.0[q]	11.6[q]	-	-
Highway	18	18	18	17	18	19	16	18	16	18	18	22	18	19	20	-	16	19	16	-	-	-	-	-	-	-	-	-
Exhaust Emissions, g/m																												
HC	0.5	0.5	0.4	0.6	0.8	0.7	0.6	0.5	0.7	0.6	0.5	1.0	0.5	0.5	0.7	-	0.6	0.7	0.5	2.5[q]	3.3[q]	3.0[q]	2.8[q]	2.8[q]	2.9[q]	3.4[q]	-	-
CO	8	8	4	8	5	3	5.3	3.7	5.5	10	6	14	4	5	11	-	3.8	4.0	5.0	22[q]	30[q]	20[q]	24[q]	27[q]	30[q]	36[q]	-	-
NO_x	2.3	2.3	2.6	3.1	2.7	2.6	1.8	1.7	1.9	2.9	3.1	2.3	2.3	2.8	2.5	-	1.6	1.9	1.2	2.7[q]	3.3[q]	2.9[q]	2.5[q]	2.4[q]	1.5[q]	2.7[q]	-	-

[a] Malibu

[b] Monte Carlo

[c] Impala

[d] Caprice

[e] Camaro

[f] Malibu wagon

[g] Nova

[h] K-10 Blazer

[i] G-10 Beauville

[j] C-10 pickup

[k] Calibrated to meet California emission standards

[m] At 14-lb/min air flow.

[n] At 2.5-lb/min air flow.

[o] At 2-lb/min air flow.

[p] At 4-lb/min air flow.

[q] 1972 FTP

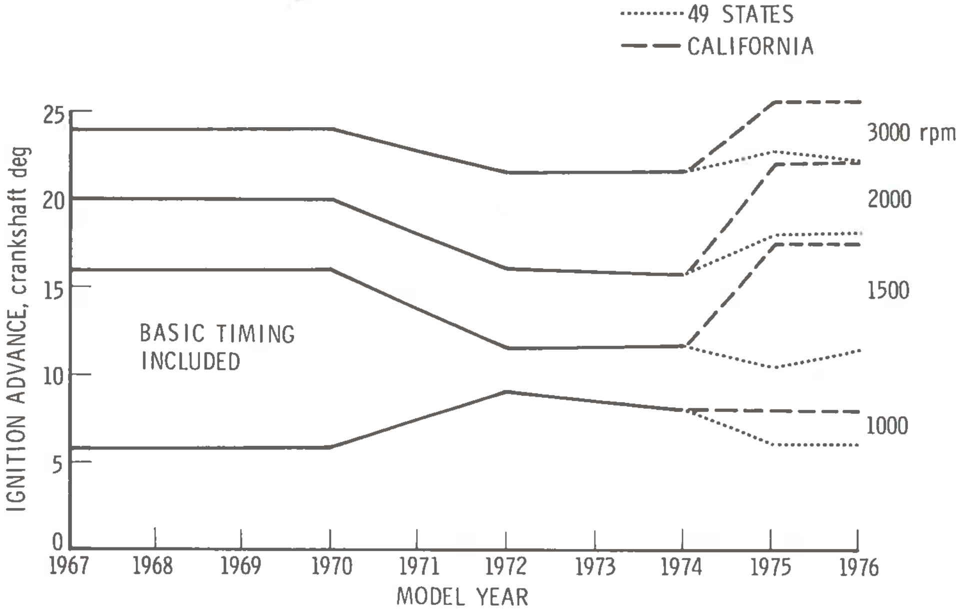


FIGURE 4-63. CENTRIFUGAL SPARK ADVANCE SCHEDULE: GM 350-CID ENGINE WITH AUTOMATIC TRANSMISSION; 4-VENTURI CARBURETOR

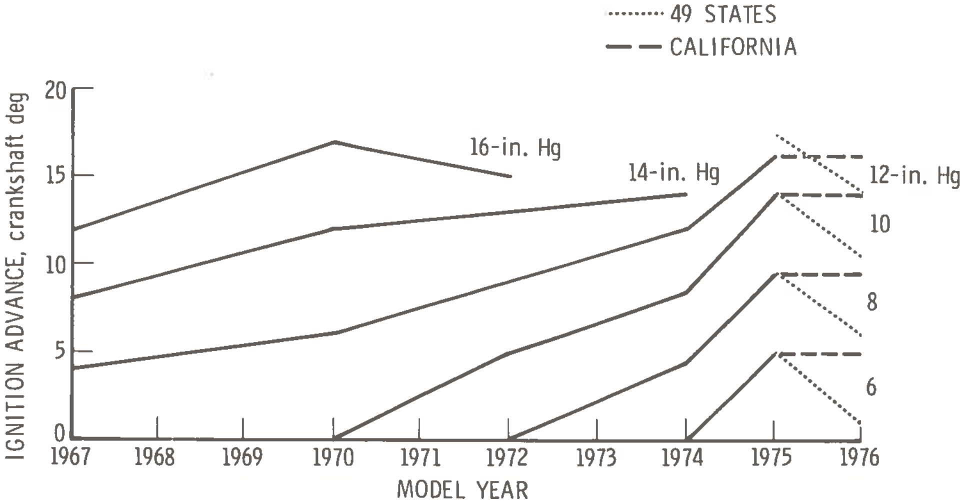


FIGURE 4-64. VACUUM SPARK ADVANCE SCHEDULE: GM 350-CID ENGINE WITH AUTOMATIC TRANSMISSION; 4-VENTURI CARBURETOR

additional advance shown in Figure 4-64 is modulated in an on-off fashion and has been used only over a relatively small part of a vehicle's city operating envelope as explained previously in Section 4.4.3.4.2.

For the last two model years, both Figures 4-63 and 4-64 show the impact of the difference in the 49-states versus California emission standards. In general, differences of 2-6 deg of centrifugal advance and approximately 4 deg of vacuum advance exist between 49-states and California models.

4.4.5.5 Exhaust Gas Recirculation

4.4.5.5.1 Design Features

Either vacuum-modulated or dual diaphragm vacuum-modulated EGR is used with the 350-CID engine. In vacuum-modulated EGR, the amount of exhaust gas admitted to the intake manifold is modulated by a valve in response to a ported vacuum signal which, in turn, is controlled by throttle position. When the throttle is closed, as when the engine is at idle, the carburetor throttle valve is closed, and there is no vacuum through the EGR vacuum line because the EGR vacuum port is above the throttle valve. If the throttle is partially open, as when the vehicle is cruising or slightly accelerating, there is a partial vacuum created in the carburetor at the EGR vacuum port. When the throttle is wide open there is little vacuum created, and the valve is closed or nearly closed. The exhaust gases follow a passage to the vacuum-controlled valve, where if the valve is open exhaust gas is released into the intake manifold to be drawn into the combustion chamber.

In systems using vacuum-modulated dual diaphragm EGR, the valve is similar to the ported signal valve, except that a second diaphragm is connected by a spacer to the original diaphragm and the diaphragms move together. Manifold vacuum, rather than ported vacuum, is applied to the volume between the two diaphragms. Since the upper diaphragm has a larger effective area than the lower diaphragm, the load caused by manifold vacuum acting between the two diaphragms is additive to the spring load. Thus, as the engine load is increased, the manifold vacuum decreases, and the combined force of the spring and the vacuum chamber is reduced, allowing the valve to open farther for a given EGR vacuum signal. Therefore, for high intake manifold vacuum, as would be experienced in cruise, the opening is less than for low manifold vacuum obtained during acceleration. This causes the dual diaphragm EGR system to provide more EGR on acceleration where loads are higher, and the tendency to produce NO_x is greater. Dual diaphragm EGR is used on full sized sedans and station wagons intended for sale in California.

4.4.5.5.2 EGR Valve Calibration

The EGR valve calibration data shown in Table 4-36 show an overall decrease in maximum flow between 1974 and 1975, with a trend toward tailoring of EGR flow to individual vehicle characteristics in 1975. In 1976, the trend is toward standardization of flow levels.

4.4.5.6 Secondary Air Injection

Secondary air injection is used on all 1974-1976 California 350-CID engines with four-venturi carburetors and on a number of 49-states units, as indicated in Table 4-33. The system is functionally the same as the one described in Section 4.4.3.6, except that for 1975 and 1976 air is injected into the exhaust system at a single point just upstream of the catalytic converter rather than into each individual exhaust valve port.

4.4.5.7 Catalytic Converter

All 1975 and 1976 Chevrolet 350-CID V-8 engines employ a 260-cu in. catalytic converter as described in Section 4.4.3.7.

4.4.5.8 Crankcase and Evaporative Emission Control System

The crankcase and evaporative emission control systems used on the subject engine are functionally the same as the configurations described in Section 3.

4.4.5.9 Fuel Economy and Emissions

Figures 4-65 and 4-66 present normalized average fuel economy histories of 350-CID engine equipped Chevrolet vehicles, derived from test data published by the EPA (Refs. 4-15 through 4-21 and 4-37 through 4-39). In the automatic transmission case, both 49-states and California vehicles show decreasing 1973 to 1974 fuel economy followed by subsequent 1975 and 1976 rises. As shown in Table 4-36, the improved fuel economy from 1974 to 1975 is attributed to increased midspeed centrifugal ignition advance, increased vacuum advance at the higher manifold vacuum levels, and decreased EGR flow. These changes apply to both California and 49-states vehicles.

The fuel economy of the California vehicles remain nearly constant between 1975 and 1976, which is to be expected considering the small

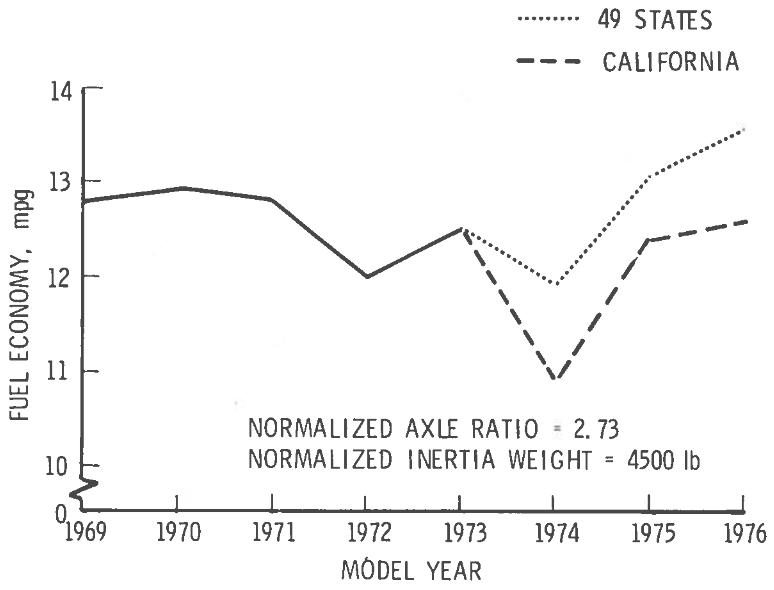


FIGURE 4-65. NORMALIZED AVERAGE CITY FUEL ECONOMY: GM 350-CID ENGINE WITH AUTOMATIC TRANSMISSION

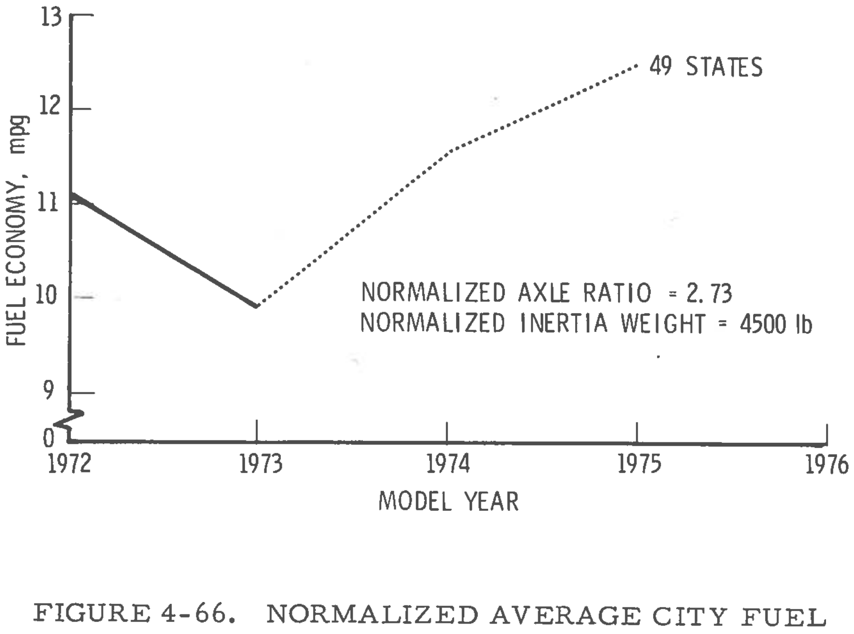


FIGURE 4-66. NORMALIZED AVERAGE CITY FUEL ECONOMY: GM 350-CID ENGINE WITH MANUAL TRANSMISSION

variations in spark timing and carburetor air/fuel ratio settings. While the fuel economy of the 49-states vehicles shows a slightly larger improvement in 1976 relative to 1975, these variations are attributed to test-to-test and hardware-to-hardware variabilities because no significant changes in spark timing, air/fuel ratio, and EGR flow rates have taken place, as shown in Table 4-36.

The normalized average fuel economy of manual transmission equipped vehicles using the 350-CID Chevrolet engine is plotted as a function of model year in Figure 4-66. Again, the fuel economy improvement from 1974 to 1975 is due to increased centrifugal and vacuum advance, combined with a reduction in EGR. Fuel economy data for 1976 manual transmission vehicles are not given in Figure 4-66 as available data are limited to low production specialty cars, which are excluded from this analysis.

4.5 REFERENCES

4-1. "Application for Certification, 1976 49-States Vehicles," Parts I and II, American Motors Corporation, Detroit, Michigan.

4-2. "Application for Certification, 1976 California Vehicles," Parts I and II, American Motors Corporation, Detroit, Michigan.

4-3. "Application for Certification, 1975 49-States Vehicles," Parts I and II, American Motors Corporation, Detroit, Michigan.

4-4. "Application for Certification, 1975 California Vehicles," Parts I and II, American Motors Corporation, Detroit, Michigan.

4-5. "Application for Certification, 1974 49-States Vehicles," Parts I and II, American Motors Corporation, Detroit, Michigan.

4-6. "Application for Certification, 1974 California Vehicles," Parts I and II, American Motors Corporation, Detroit, Michigan.

4-7. "Application for Certification, 1972 49-States Vehicles," Parts I and II, Detroit, Michigan.

4-8. 1975 American Motors Corporation Technical Service Manual, Detroit, Michigan.

4-9. 1974 American Motors Corporation Technical Service Manual, Detroit, Michigan.

4-10. 1973 American Motors Corporation Technical Service Manual, Detroit, Michigan.

4-11. 1972 American Motors Corporation Technical Service Manual, Detroit, Michigan.

4-12. 1970 American Motors Corporation Technical Service Manual, Detroit, Michigan.

4-13. 1967 American Motors Corporation Technical Service Manual, Detroit, Michigan.

4-14. W. A. Daniel and J. T. Wentworth, "Exhaust Gas Hydrocarbons-Genesis and Exodus," SAE Paper No. 486B, SAE National Automobile Week, SAE Technical Progress Series, 6, Vehicle Emissions, Detroit, Michigan, Society of Automotive Engineers, New York (March 1962), pp. 192-196.

4-15. EPA/FEA 1976 Gas Mileage Guide for New Car Buyers, U.S. Environmental Protection Agency (October 17, 1975).

4-16. Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines; Federal Certification Test Results for 1976 Model Year, U.S. Environmental Protection Agency.

4-17. EPA/FEA 1975 Gas Mileage Guide for New Car Buyers; Control of Air Pollution for 1975, U.S. Environmental Protection Agency (February 1, 1975).

4-18. "Model Year New Motor Vehicles and New Motor Vehicle Engines," Federal Register, Part III, Vol. 40, No. 48, (March 11, 1975).

4-19. "Control of Air Pollution from New Motor Vehicles and Engines," Federal Register, Vol. 38, No. 212, Part II (November 5, 1973).

4-20. 1974 Gas Mileage Guide for Car Buyers, U.S. Environmental Protection Agency (February 1974).

4-21. "Control of Air Pollution from New Motor Vehicles and Engines," Federal Register, Vol. 38, No. 84, Part II (May 2, 1973).

4-22. Personal communication with American Motors Corporation.

4-23. "Application for 1976 Model Year Certification of Light Duty Motor Vehicles to Comply With Federal Standards," Parts I and II, Chrysler Corporation, Detroit, Michigan (1974/1975).

4-24. "Application for 1976 Model Year Certification of Light Duty Motor Vehicles to Comply With California Standards," (Parts I and II, Chrysler Corporation, Detroit, Michigan (1974/1975).

4-25. "Application for 1975 Model Year Certification of Light Duty Motor Vehicles to Comply With Federal Standards," Parts I and II, Chrysler Corporation, Detroit, Michigan (1973/1974).

4-26. "Application for 1975 Model Year Certification of Light Duty Motor Vehicles to Comply With California Standards," Parts I and II, Chrysler Corporation, Detroit, Michigan (1973/1974).

4-27. "Application for 1974 Model Year Certification of Light Duty Motor Vehicles to Comply With Federal Standards," Parts I and II, Chrysler Corporation, Detroit, Michigan (1972/1973).

4-28. "Application for 1974 Model Year Certification of Light Duty Motor Vehicles to Comply With California Standards," Parts I and II, Chrysler Corporation, Detroit, Michigan (1972/1973).

4-29. "Application for 1972 Model Year Certification," Chrysler Corporation, Detroit, Michigan (1971).

4-30. "Application for 1970 Model Year Certification," Chrysler Corporation, Detroit, Michigan (1969).

4-31. Personal communication with Chrysler personnel.

4-32. 1967, 1972, 1974 and 1975 Chrysler Corporation, Dodge and Plymouth Chassis Service Manuals, Chrysler Corporation, Detroit, Michigan.

4-33. "Distributor Spark Advance Curves for 1967 U.S. Passenger Cars," Ethyl Corporation, Ferndale, Michigan.

4-34. "Distributor Spark Advance Curves for 1970 U.S. Passenger Cars," Ethyl Corporation, Ferndale, Michigan.

4-35. "Distributor Spark Advance Curves for 1968 U.S. Passenger Cars," Ethyl Corporation, Ferndale, Michigan.

4-36. D. A. Hurter, et al, A Study of Technological Improvements in Automobile Fuel Consumption, Report No. DOT-TSC-OST-74-40, Department of Transportation, Washington, D.C., prepared by Arthur D. Little, Inc., Cambridge, Massachusetts (December 1974).

4-37. A Study of Emissions from 1966 - 1972 Light Duty Vehicles in Los Angeles and St. Louis, EPA Report No. APTD-1505, U.S. Environmental Protection Agency; prepared by Automotive Environmental Systems, Inc., Westminster, California (August 1973).

4-38. *A Study of Emissions from Light Duty Vehicles in Denver, Houston and Chicago*, EPA Report No. APTD-1504, U. S. Environmental Protection Agency; prepared by Automotive Testing Laboratories, Inc., Aurora, Colorado (July 1973).

4-39. *A Study of Emissions from Light Duty 1966-1972 Vehicles in Washington, D. C.*," Second Edition; EPA Report No. APTD-1506, U. S. Environmental Protection Agency; prepared by General Environments Corporation, Springfield, Virginia (January 1974).

4-40. *Automobile Exhaust Emission Surveillance Analysis of the FY 72 Program*, EPA Report No. EPA-460/2-74-001, U. S. Environmental Protection Agency, Ann Arbor, Michigan (February 1974).

4-41. Personal communication with Mr. J. D. Murrell, EPA, Ann Arbor, Michigan.

4-42. T. A. Huls, et al., "Evolution of Federal Light Duty Mass Emission Regulations," SAE Paper No. 730554, Society of Automotive Engineers, New York (May 14-18, 1973).

4-43. "Preliminary Application for 1974 Model Year Certification of Light Duty Motor Vehicles to Comply With Federal Standards," Parts I and II, Ford Motor Company, Dearborn, Michigan (1972).

4-44. "Preliminary Applications for 1974 Model Year Certification of Light Duty Motor Vehicles to Comply With California Standards," Parts I and II, Ford Motor Company, Dearborn, Michigan (1972).

4-45. "Preliminary Application for 1975 Model Year Certification of Light Duty Motor Vehicles to Comply With Federal Standards," Parts I and II, Ford Motor Company, Dearborn, Michigan (1973).

4-46. "Preliminary Application for 1975 Model Year Certification of Light Duty Motor Vehicles to Comply With California Standards," Parts I and II, Ford Motor Company, Dearborn, Michigan (1973).

4-47. "Preliminary Application for 1976 Model Year Certification of Light Duty Motor Vehicles to Comply With Federal Standards," Parts I and II, Ford Motor Company, Dearborn, Michigan (1974).

4-48. "Preliminary Application for 1976 Model Year Certification of Light Duty Motor Vehicles to Comply With California Standards," Parts I and II, Ford Motor Company, Dearborn, Michigan (1974).

4-49. Ford 1974 Car Shop Manual, Vol. II, Engine, Ford Marketing Corporation, Dearborn, Michigan (February 1974).

4-50. Ford 1975 Car Shop Manual, Vol. II, Engine, Ford Motor Company, Dearborn, Michigan (1975).

4-51. A. C. Malliaris, E. Withjack, and H. Gould, "Simulated Sensitivities of Auto Fuel Economy, Performance, and Emissions," SAE Paper No. 760157, presented in Detroit, Michigan, Society of Automotive Engineers, New York (February 23-27, 1976).

4-52. A. C. Malliaris, H. Hsia, and H. Gould, "Concise Description of Auto Fuel Economy and Performance in Recent Model Years," SAE Paper No. 760045, Society of Automotive Engineers, New York (February 23-27, 1976).

4-53. Private communication with Ford Motor Company, Dearborn, Michigan.

4-54. Ford 1970 Car Shop Manual, Vol. II, Engine, Ford Marketing Corporation, Dearborn, Michigan.

4-55. G. J. Huebner and D. J. Gasser, "Energy and the Automobile - General Factors Affecting Vehicle Fuel Consumption," SAE Paper No. 750958, Society of Automotive Engineers, New York (1975).

4-56. J. D. Murrell, "Factors Affecting Fuel Economy," SAE Paper No. 750958, Society of Automotive Engineers, New York (1975).

4-57. "Distributor Spark Advance Curves for 1969 U. S. Passenger Cars," Ethyl Corporation, Ferndale, Michigan.

4-58. "Distributor Spark Advance Curves for 1970 U. S. Passenger Cars," Ethyl Corporation, Ferndale, Michigan.

4-59. "Application for Certification, 1976 49-States Vehicles," Parts I and II, General Motors Corporation, Detroit, Michigan.

4-60. "Application for Certification, 1976 California Vehicles," Parts I and II, General Motors Corporation, Detroit, Michigan.

4-61. "Application for Certification, 1975 49-States Vehicles," Parts I and II, General Motors Corporation, Detroit, Michigan.

4-62. "Application for Certification, 1975 California Vehicles," Parts I and II, General Motors Corporation, Detroit, Michigan.

4-63. "Application for Certification, 1974 49-States Vehicles," Parts I and II, General Motors Corporation, Detroit, Michigan.

4-64. "Application for Certification, 1974 California Vehicles," Parts I and II, General Motors Corporation, Detroit, Michigan.

4-65. "Application for Certification, 1972 49-States Vehicles," Parts I and II, General Motors Corporation, Detroit, Michigan.

4-66. "Application for Certification, 1972 California Vehicles," Parts I and II, General Motors Corporation, Detroit, Michigan.

4-67. *Chevrolet Service and Overhaul Manual Supplement, 1975 Vega and Monza 2 + 2*, General Motors Corporation, Detroit, Michigan.

4-68. *Chevrolet Service and Overhaul Manual, 1974 Vega*, General Motors Corporation, Detroit, Michigan.

4-69. *Chevrolet Shop Manual, 1972 Vega*, General Motors Corporation, Detroit, Michigan.

4-70. *Chevrolet Service and Overhaul Manual Supplement, 1975 Chevrolet, Chevelle, Camero, Monte Carlo, Nova, Corvette*, General Motors Corporation, Detroit, Michigan.

4-71. *Chevrolet Overhaul Manual, 1974 Passenger Cars and Light Duty Trucks*, General Motors Corporation, Detroit, Michigan.

4-72. *Chevrolet Overhaul Manual, 1972 Passenger Cars and 10-30 Series Trucks*, General Motors Corporation, Detroit, Michigan.

4-73. *Chevrolet Chassis Overhaul Manual, 1970 Passenger Cars, 10-60 Series Trucks and 1969 Corvette*, General Motors Corporation, Detroit, Michigan.

4-74. *Chevrolet Chassis Overhaul Manual, 1967 Chevrolet, Chevelle, Camero, Chevy II, Corvette*, General Motors Corporation, Detroit, Michigan.

4-75. Personal communication with EPA.