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SURVEY OF DRIVER AID DEVICES FOR IMPROVED FUEL ECONOMY

M.G. Hinton
L. Forrest
D.P. Duclos
T.H. Davey
R.R. Sheahan
K.B. Swan

Aerospace Corporation
Environmental and Energy Conservation Division
El Segundo CA 90245

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16. Abstract

This report presents a brief summarization of available information pertaining to devices offered to aid the driver in improving his driving habits in order to reduce fuel consumption.

Principal emphasis is placed on characterizing the available devices in terms of their features and operating principles. When appropriate, possible side effects (e.g., safety considerations) occasioned by the use of such devices are examined. The available fuel economy test data for drivers who had received training only (no auxiliary or aid devices) are reviewed for comparison purposes.

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PREFACE

This report was prepared by the staff of the Mobile Systems Group of The Aerospace Corporation, El Segundo, California, for the U. S. Department of Transportation (DOT), Transportation Systems Center (TSC). The work was done at the direction of the Biotechnology Division of TSC. It is part of a larger examination of methods for reducing automotive fuel consumption in the existing fleet of automobiles. The DOT sponsor is the Office of the Secretary. Work on this study commenced in July 1975.

The report presents the results of a review of devices offered to aid the driver in improving his driving habits in order to reduce fuel consumption, and is based on information acquired and evaluated through September 1975. The emphasis is on devices that have been brought to the attention of the DOT as having the potential to improve automotive fuel economy.

The report also contains a discussion of the general principles and interrelationships influencing automotive fuel economy, including vehicle weight, engine size, use of accessories, and trip characteristics. Available data concerning the influence of driving habits on fuel economy are also summarized. This information provides a comparative basis for the evaluation of the driver aid devices considered and for the assessment of their relative efficacy.

Appreciation is acknowledged for the guidance and assistance provided by Mr. Philip Davis and Dr. M. Stephen Huntley, Jr., of the Department of Transportation, Transportation Systems Center, who served as DOT/TSC Technical Monitors for this study.

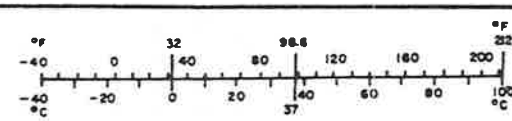
METRIC CONVERSION FACTORS

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

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



CONTENTS

CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

LIST OF ILLUSTRATIONS (continued)

LIST OF TABLES

1. SUMMARY

A survey and an evaluation were made of the characteristics of various driver aid devices in order to determine which types of devices have the highest potential for changing driving and travel habits to improve automotive fuel economy. These devices include vacuum gages, flowmeters, engine and vehicle speed monitors, and throttle position monitors.

A review was conducted of the available descriptive material and test data for selected devices; the data were acquired from auto makers, government agencies, and industrial companies. Principal emphasis was placed on characterizing the devices in terms of their features and operating principles. Where appropriate, possible side effects (e.g., safety considerations) occasioned by their use were examined. Fuel economy test data for drivers who had received training but drove without auxiliary instrumentation were reviewed for comparison purposes.

There are insufficient test data to adequately evaluate the fuel economy advantages of vehicles with any of the driver aid devices surveyed. Where data were provided, they were often of such nature that they could have been significantly affected by traffic flow conditions or by the test driver's motivation. In addition, most data provided were from single vehicles tested under limited conditions and, thus, provide a poor basis from which to generalize to other driving situations.

Because of the lack of reliable data, the evaluations of the devices were based upon their apparent usefulness as estimated from their design and operational principles rather than from actual demonstrations of effectiveness.

The following are brief highlights summarizing the major findings of the study activities.

1.1 DEVICES CONSIDERED AND THEIR CHARACTERISTICS

The types of driver aid devices considered included the following:

a. Manifold vacuum gages
b. Miles-per-gallon (MPG) meters
c. An accelerator pedal feedback system
d. Accelerometers
e. Pyrometers
f. Speed-warning devices
g. Throttle position devices
h. Automatic cruise controls
i. Fuel flowmeters and totalizers
j. Speedographs and tachographs
k. Air flowmeters

These devices are shown in Table 1-1, with summaries of their operating principles and use characteristics.

1.2 IMPACT OF DRIVING HABITS AND TECHNIQUES ON FUEL ECONOMY

The interest in driver aids stems in large measure from the effect of driving habits on fuel economy. Table 1-2 summarizes available data concerning this impact.

1.2.1 Shell, Mobil, and TSC/NHTSA Tests

The Shell, Mobil, and TSC/NHTSA tests shown were all directed toward determining the impact of driver training on fuel economy, and each program used a single car over a designated test route, but with a multiplicity of drivers; 23 for Shell, 20 for Mobil, and 20 for TSC. The Shell program stressed coaching in gas-saving techniques; Mobil merely provided a driving instruction manual for reading; and the TSC program involved a one-hour training session. These three test programs indicated fuel economy improvements from 8.9 percent to 15 percent for these driver training methods. In

TABLE 1-1. SUMMARY OF DRIVER AID DEVICES

Class and Type of Device	Engine or Vehicle Parameter Sensed	Type of Aid Provided to Driver	Actions and/or Knowledge Required of Driver to Use Device	Cost
o Manifold Vacuum Gages / Dial Readout, in. Hg	Intake Manifold Vacuum, in. Hg.	Continuous display of manifold vacuum on dial over all driving conditions.	Requires at minimum that driver know that high vacuum readings generally indicate fuel-efficient operation, and that readings below ~10 in. Hg. indicate uneconomical acceleration conditions. Driver must monitor instrument readout and reduce accelerator pedal pressure to reduce acceleration and/or reduce vehicle speed.	$5 to $35
/ Color Range Readout		Multiple colored zones on dial which represent poor, fair, and good economy as well as a deceleration zone.	Driver must attempt to keep in best fuel economy zone or light area during driving by changing accelerator pedal pressure to reduce acceleration leval and/ or decrease vehicle speed.	
/ Multiple Colored Lights		Multiple colored lights corresponding to best, good, fair, and poor fuel economy.		
/ Single Light (Continuous or Flashing) . Dash-mounted . Fender-mounted		Light system is preset to warn driver when vacuum falls below 5 to 10 in. Hg. and thus indicate high fuel consumption conditions.	Driver must reduce accelerator pedal pressure until light turns off.	
/ Two-color Linear Piston Readout		Linear piston preset to change in color from yellow to blue when vacuum falls to 5 to 10 in. Hg range to indicate high fuel consumption conditions. Also incorporates an audible warning of onset of high fuel consumption conditions.	Driver must reduce accelerator pedal pressure until piston color changes to yellow.	

TABLE 1-1. SUMMARY OF DRIVER AID DEVICES (Continued)

Class and Type of Device	Engine or Vehicle Parameter Sensed	Type of Aid Provided to Driver	Actions and/or Knowledge Required of Driver to Use Device	Cost
o Vehicle Speed Devices / Speed-warning Devices . Red Light . Audible Buzzer or Siren . Green, Amber, and Red Lights with Siren . Flashing Turn Signals	Vehicle Speed, mph	Notifies driver with light and/or audio signal when preset speed level has been reached.	Driver must reduce accelerator pedal pressure until sound or light goes off. If unit is to be preset for fuel economy, driver must know economical cruise speed range.	$10 to $30
o Fuel Flow Devices / Flowmeters	Gasoline Flow Rate, gal/hr	Direct indication of rate at which fuel is being used.	Driver must scan instrument and adjust vehicle speed and/or acceleration (via accelerator pedal pressure) to obtain minimum fuel flow rate consistent with driving condition or need.	$50 to $150
/ Flow Totalizer	Total Gasoline Amount Used in Checked Interval, gal.	Permits driver to compare speeds, routes, etc., as to total amount of fuel used and then select best speed, route, etc.	Requires reading indicator at end of trip, recording results, and resetting for next trip.	$56 to $110
o Acceleration Devices / Accelerometers . Calibrated in g's	Vehicle Acceleration Rate, g's	Direct indication of vehicle acceleration rate in g's.	Driver must scan readout, have knowledge of g levels acceptable for economical acceleration, and adjust accelerator pedal pressure to avoid excessive g values.	$30 to $130
. Green, Yellow, and Red Lights		Colored lights indicating low, medium, and high acceleration rates.	Driver must modulate accelerator pedal pressure to keep light on (green) that indicates low acceleration rate.	

TABLE 1-1. SUMMARY OF DRIVER AID DEVICES (Continued)

Class and Type of Device	Engine or Vehicle Parameter Sensed	Type of Aid Provided to Driver	Actions and/or Knowledge Required of Driver to Use Device	Cost
o Miles-per-gallon (MPG) Meters / Dial Readout	Vehicle Fuel Economy, mpg (by measuring vehicle speed and fuel flow rate)	Direct readout of vehicle fuel economy (mpg) while driving.	Driver must scan instrument and adjust vehicle speed and/or acceleration (via accelerator pedal pressure) to obtain highest mpg reading consistent with driving condition or need. Driver needs to know basic speed vs. fuel economy relationship to fully appreciate mpg readings in lower portion of speed range (0 to 30 mph).	\$39 to \$150
o Exhaust Manifold Temperature Devices / Pyrometers	Exhaust Gas Temperature	Direct readout of exhaust gas temperature. (Currently used by commercial fleet operators, most commonly in diesel engine applications.)	Driver must scan instrument; generally instructed to maintain temperature within 700°F to 1200°F band by adjusting accelerator pedal pressure. Low temperature limit means inefficient low speed operation; maximum temperature limit means excessive engine loads/speeds.	\$72 to \$184
o Recording Devices / Speedographs / Tachographs	Engine Speed, Vehicle Speed, Distance, Vehicle Motion, etc. Versus Time Base	Provides continuous recording of driving behavior. Provides no aid to driver during present trip. Used by supervisor to illustrate driving deficiencies and demonstrate where improvements are needed. Used in fleet-type operations.	None	\$89 to \$372 (varies with number of parameters recorded and number of days per recording).
o Throttle Position Devices / Mechanical Hand Throttle / Electronic Pre-set Device	Vehicle Speed, mph	Permits driver to set throttle for desired cruise speed on a level road.	Driver must set device and release or override it (by touching brake pedal or pressing down on accelerator pedal) when traffic conditions demand.	\$2.50 to \$20

TABLE 1-1. SUMMARY OF DRIVER AID DEVICES (Continued)

Class and Type of Device	Engine or Vehicle Parameter Sensed	Type of Aid Provided to Driver	Actions and/or Knowledge Required of Driver to Use Device	Cost
o Accelerator Pedal Feedback / Vacuum-operated Bellows on Throttle Linkage	Engine Manifold Vacuum	Offers increased resistance to accelerator pedal movement when engine vacuum levels are low (high vehicle acceleration rates or power demand).	Driver must know what the increased pedal resistance implies. He must also know that the unit can and should be overriden in driving situations where safety considerations dictate increased acceleration and/or speed.	$30
o Cruise Controls / Vacuum-operated / Electronically operated	Vehicle Speed, mph	Permits driver to pre-set a desired cruising speed; device then automatically commands throttle position to maintain that speed.	Driver must set device. He must also release or override unit (by touching a brake or pressing down on accelerator pedal) when traffic conditions demand.	$90 to $112
o Air Flow Rate Device	Engine Air Flow Rate, cfm	Direct indication of rate at which air is being consumed.	Driver must scan instrument and adjust vehicle speed and/or acceleration (via accelerator pedal pressure) to obtain minimum air flow rate consistent with driving condition or need.	$50 to $592

TABLE 1-2. FUEL ECONOMY VERSUS DRIVING HABITS—TEST RESULTS

Company/ Agency	Purpose of Test	Results of Test
Shell Oil Company	Improvement due to coaching in gas saving techniques (23 drivers, 1 car, 22.3-mile course)	8.9% improvement over well-tuned car with radials
Auto Club of Southern California	Determine effect of acceleration levels (1 driver, 20 cars, 1/4 mile, standing start to 40-mph speed)	12.4% loss due to "moderate" acceleration 27.2% loss due to "heavy" acceleration
Mobil Oil Corporation	Improvement due to reading driving instruction manual (20 drivers, 1 car, 18-mile course)	15% improvement
	Effect of using vacuum gage after reading manual (8 drivers, 1 car, 18-mile course)	1% improvement over 15% achieved by reading only
Auto Club of Michigan	Determine effect of bad driving habits as compared to good driving techniques (22.8-mile commuter route, 10-mile expressway route, 1 car)	44% loss due to bad driving on commuter route 23% loss due to bad driving on expressway route
Douglas Aircraft Company	Determine impact of driver training program on fleet drivers. Instruction in driving techniques and training in vehicles equipped with MPG meter, vacuum gage, pyrometer (15-driver test group)	22.1% improvement due to training program with 15 drivers
TSC/NHTSA	Pilot test to determine impact of training (10 drivers with no training, 10 drivers with 1 hour training, 9-mile route, 1 car)	~10% improvement for driver with 1 hour of training

the Mobil test, a second series of tests with a vacuum gage, after drivers read the training manual, produced an additional one percent improvement.

1.2.2 Douglas Program and Southern California and Michigan Auto Club Tests

The Douglas program is a more comprehensive program dealing with fleet drivers only. They are not only given instruction in driving techniques, but also trained in vehicles equipped with various driver aids. Douglas reports a 22 percent improvement with a 15-driver test group. The two auto club tests referenced, Southern California and Michigan, were made to illustrate the effects of "bad" rather than "good" driving habits, and tend to show that high accelerations and excessive speeds can result in fuel economy penalties from 12 to 44 percent, depending upon the degree of "bad" driving and the driving route.

1.2.3 Fuel Economy Improvement Potential

Although the data base is limited, these tests indicate a potential for 10 to 15 percent improvement in fuel economy because of fuel-efficient driving habits. The auto club data tend to indicate excessive acceleration is an important factor in poor fuel economy.

1.3 AVAILABLE DRIVER AID TEST DATA

Test data are available for only two classes of driver aid devices: manifold vacuum gages and an accelerator pedal feedback system.

1.3.1 Manifold Vacuum Gages

The available test data for manifold vacuum gages are shown in Table 1-3. The Econ-O-Lite, a flashing light unit, was tested by the Postal Service on seven one-half-ton and one-quarter-ton trucks, with three of the trucks having a fuel economy improvement. Employees of a Detroit TV station tested their personal cars (Pontiac, Ford, and Plymouth) with factory-equipped vacuum gages, and noted improvements from 6.9 to nearly 25 percent in fuel economy. Most of the available data concern the Accelerite, a two-color linear piston vacuum gage. As can be noted in Table 1-3, fuel economy improvements for this device ranged from 3 to 17 percent.

It should be emphasized that all of the data shown in Table 1-3 are based on very limited tests, and that it is impossible to isolate the effects of the vacuum gage from any driving instructions that may have been given to the drivers. It is felt that motivation on the part of the driver may be an extremely important factor in such tests. In this regard, it should be noted that some of the poorer or more negative results shown in Table 1-3 involved fleet vehicle drivers.

1.3.2 Accelerator Pedal Feedback System

The accelerator pedal feedback system is the TEST Gas Saver. It consists of a vacuum-operated bellows on the throttle linkage that offers increased resistance to accelerator pedal movement when engine vacuum levels are low (high vehicle acceleration rates or high power demand). The driver must appreciate what the increased pedal resistance implies, and that the unit can and should be overridden in driving situations where safety conditions dictate the use of increased acceleration or speed.

There are test data from two sources. The U.S. Postal Service installed the device on five one-quarter-ton trucks. One truck achieved a 5.1 percent increase in miles per gallon; four trucks decreased in fuel economy from 2.3 to 25.3 percent; and a baseline control truck without the device showed no change in fuel economy.

The device manufacturer has tested the device on seven automobiles and claims an average fuel economy improvement of 20.6 percent.

1.4 RELATIVE EFFICACY OF VARIOUS DRIVER AID DEVICES

Many of the driver aid devices shown in Table 1-1 can be postulated, in principle, to enable a driver to change his driving habits to improve fuel economy. The efficacy of any device in this regard would, of course, depend on the specific driver, his normal driving patterns or routes, and the degree to which he is motivated to use a particular device. As noted previously,

TABLE 1-3. MANIFOLD VACUUM DEVICES—TEST DATA[a,b,c]

Device	Tested By	Vehicle	Fuel Economy Results
Econ-O-Lite	Postal Service	One 1/2-ton truck	$\sim$0.1 mpg improvement
		Six 1/4-ton trucks	$\sim$1.0 mpg improvement for 2 of 6 trucks
Pontiac Vacuum Gage	Employees of WWJ-TV, Detroit	Pontiac	6.9% improvement
Ford Vacuum Gage		Ford	24.6% improvement
Plymouth Fuel Pacer		Plymouth	23.1% improvement
Accelerite	Ryder Truck Lines		10.2% improvement
	Postal Service	One 1/2-ton truck	3% improvement
		One 1/2-ton truck	7% improvement
	S. V. Shelton, Georgia Institute of Technology	5 vehicles	11.37% average improvement (between 8.5 and 13.6% with 95% confidence level)
	City of Jacksonville, Florida	Five 1/2-ton trucks	17% improvement
	National Park Service	Four vehicles	10% improvement

[a]Above tests all very limited

[b]Impossible to separate effects of device and instructions

[c]Motivation may be extremely important factor (more negative results involved fleet vehicles)

there are insufficient test data to evaluate these possibilities for even a single device at this time. Until such data are available, fuel economy improvement claims should be viewed with caution.

1.4.1 Excessive Acceleration Indicators

It would appear that those devices that enable the driver to refrain consistently from excessive accelerations (thereby avoiding initial cruise conditions too high for existing traffic flow, and avoiding excessive deceleration and braking maneuvers) would have high potential for improving fuel economy. These devices include the following:

a. Manifold vacuum gages
b. Accelerator pedal feedback devices
c. Accelerometers
d. Miles-per-gallon (MPG) meters
e. Pyrometers

The manifold vacuum gage provides a visual signal when excessive vehicle acceleration rates may be imminent or in process, permitting the driver to reduce accelerator pedal pressure to remain within acceptable acceleration limits. The accelerator pedal feedback device requires the driver to push harder on the accelerator pedal as the throttle opening increases, thus warning him directly by a physical force requirement that he may be trying to accelerate too fast. Accelerometers directly measure and provide a visual readout of vehicle acceleration rate; the driver, therefore, must have knowledge of what acceptable g levels are. Similarly, pyrometers require detailed knowledge on the part of the driver as to the interrelationship of exhaust gas temperature and engine load and vehicle speed characteristics in order to utilize this device effectively to control vehicle acceleration. Merely scanning the pyrometer to assure that temperature levels are between predetermined high and low levels may, however, provide some combined measure of acceleration and steady-state speed control. The MPG meter, when used for acceleration control at low speeds, requires that the driver more closely scan the instrument because of the normally low MPG readings associated with the 0 to 30 mile-per-hour speed range of automobiles. This instrument more clearly conveys the fuel consumption effect of acceleration at the higher speed conditions.

1.4.2 Vehicle Speed Control Devices

Those devices whose principal function is related to vehicle speed control or selection are considered of less utility for saving fuel. They include speed-warning devices, throttle-position setting devices, automatic cruise controls, and the MPG meter. The amount of fuel economy improvement afforded by such cruise speed control is felt to be small because of the following: (1) the current 55 mile-per-hour speed limit, (2) the fact that the speedometer is readily visible for first-order speed control, and (3) the fact that in many traffic situations the driver is constrained by safety considerations to follow the average speed conditions of the existing traffic.

1.4.3 Metering Devices

Those devices providing metering or other auxiliary functions require comparative knowledge on the part of the driver in order to change driving conditions to reduce fuel consumption. They include fuel and air flowmeters, the fuel totalizer, the MPG meter, speedographs, and tachographs. The totalizers, speedographs, and tachographs, while of potential utility to a driver in assessing overall driving habits, do not provide an action-oriented signal to the driver during actual driving.

1.4.4 Attentional Requirements

The driver must respond to the output of a device in a timely manner in order to reap any potential benefits of the device. The amount of scanning required to monitor effectively the device displays is not quantified for any of these devices. It would be expected to vary from driver to driver as a function of perceptiveness, peripheral vision acuity, and general ability to correlate the many variables encountered during normal driving situations. If a driver were required to focus too much attention on the readout, it could affect driving safety. Device placement, size, and readability, for example, do influence the attentional requirements of the device and therefore have safety implications. Driver training may be required with any device to reduce excessive scanning and its impact on traffic safety.

1.4.5 Fleet Driver Motivations

The foregoing summary statements were principally directed to the technical characteristics of the devices and assumed that, in some manner, the driver would or could be motivated to use them. Available information suggests that motivational factors for the general driving public and for professional fleet drivers may be totally different, and as a consequence, that ideal driver aid devices or device combinations for these two groups may be different.

Operators who have instituted driver training programs for fleet drivers who drive vehicles instrumented with driver aids (e.g., MPG meter, manifold vacuum gage, and exhaust temperature pyrometer), feel that it is essential also to incorporate speedographs or tachographs in order to monitor the driving habits of the individual drivers. The presence of tell-tale graphic records continuously recording driver performance motivates the driver to adhere to fuel-efficient driving practices, at the risk of disciplinary measures.

1.5 CONCLUSIONS AND RECOMMENDATIONS

The available driver-training-only test data show the potential for a 10 to 15 percent improvement in fuel economy because of improved driving habits. Data from manifold-vacuum device tests show a similar potential for fuel economy improvement. However, the data currently available on the effectiveness of driver aids are poor in all reported cases. The studies which produce the data are usually demonstrations rather than controlled experiments.

Those devices that enable a driver to refrain consistently from excessive vehicle acceleration rates appear to offer the most potential for saving fuel.

Costs related to the effective use of the aid device are not clear at this time. While a vacuum gage, for example, may be relatively inexpensive, the costs associated with training the driver to use it have not been determined.

Adequate controlled evaluation tests are necessary to quantify more accurately the fuel savings to be expected from the use of driver aids and to quantify associated education, training, and implementation costs.

2. INTRODUCTION

The recent embargo on petroleum exports to the United States by the oil-producing countries of the Middle East has amply demonstrated that automotive fuel shortages in the United States could occur again at any time in the future unless and until the United States becomes self-sufficient with regard to automotive fuel needs. As a result, many concerned people have been postulating various methods for reducing automotive fuel consumption in order to lessen the national demand for petroleum, for both the existing vehicle fleet and future new car models. The need for improving the fuel economy of the existing vehicle fleet would appear to be particularly important in view of the long lead time required to implement new technology in new vehicles. Any such benefits because of more efficient operation of existing vehicles would be additive to benefits accruing from the introduction of new technology and from changes in the vehicle size and weight mix occasioned by the increased usage of smaller, lighter vehicles.

The United States Department of Transportation is conducting an evaluation of methods to reduce fuel consumption in the existing auto fleet. As part of this program, The Aerospace Corporation performed the present study, which is a technical evaluation of various available driver aid devices.

Driver aid devices are gages, lights, or other instruments that provide information to the driver which may assist him in correcting his driving habits so as to improve vehicle fuel economy. The devices themselves do not directly affect the car's fuel economy or performance in any way.

The purpose of this study effort was to survey and evaluate the characteristics of the various driver aid devices that have been postulated to offer improved vehicle fuel economy, to determine which class of devices has the best potential for improving fuel economy, and to identify meaningful control variables or other factors that should be considered in structuring a test program for experimental verification of the fuel economy improvement potential of driver aid devices.

The study addressed driver aid devices within the general classes of vacuum gages, flowmeters, engine speed monitors, vehicle speed monitors, and throttle position monitors. It is planned that the results of this study will be used to aid in structuring a field evaluation test program.

3. FACTORS AFFECTING VEHICLE FUEL ECONOMY

During steady-state cruise speeds, fuel economy is principally related to speed, car size and weight, engine size, and accessories used. The driver only has the option of selecting the most economical cruise speed when traffic conditions permit. During cyclic driving conditions, for a given car, the fuel economy is a function of the number of stops and starts, rates of acceleration and deceleration, idling time, and frequency of cold-start conditions. The driver has some control over these factors through good driving techniques; however, traffic conditions do limit the degree of control.

Appendix A contains a detailed discussion of the above factors and interrelationships influencing automobile performance and fuel economy. This section of the report discusses typical engine-vehicle operating parameters, the impact of vehicle acceleration rate on fuel economy, factors under control of the driver, and a review of available driver fuel economy test results.

3.1 TYPICAL ENGINE-VEHICLE OPERATING PARAMETERS

3.1.1 Steady-State Characteristics

Representative engine characteristics for a 1967-1968 intermediate-size passenger automobile operating on a level road at steady-state cruise conditions are shown in Figures 3-1 and 3-2. Although the incorporation of emission controls on later model vehicles (e.g., retarded timing, exhaust gas recirculation, and lowered compression ratio) would change the absolute values of these parameters somewhat (e.g., retarded timing increases specific fuel consumption and exhaust gas recirculation reduces manifold vacuum levels), they are considered sufficiently representative for purposes of illustration and general discussion.

The revolutions-per-minute (rpm) parameter displayed in Figure 3-1 assumes operation in high gear over the complete range of road speed, and neglects slight nonlinearities in the low end of the speed range caused by automatic transmission and other drive train inefficiencies.

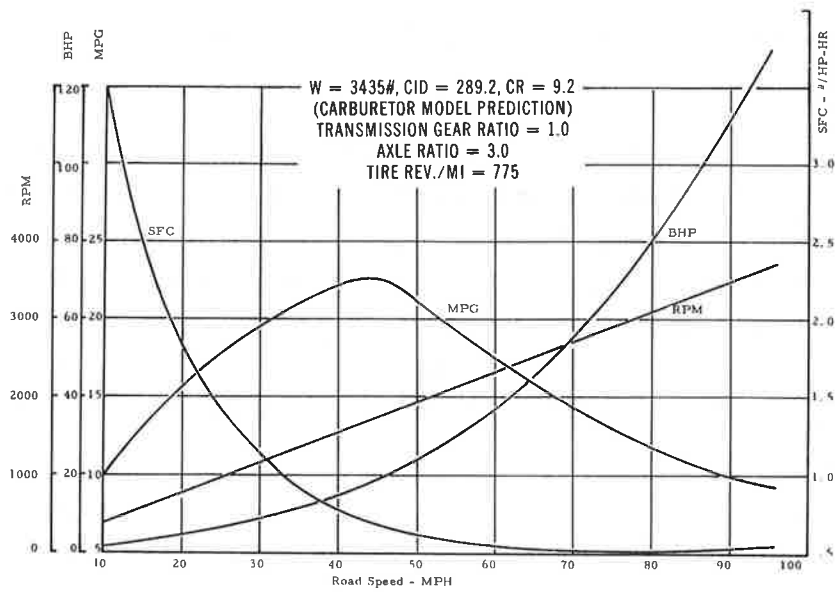


Figure 3-1. Engine Performance Characteristics for 1967-1968 Ford (Ref. 3-1)

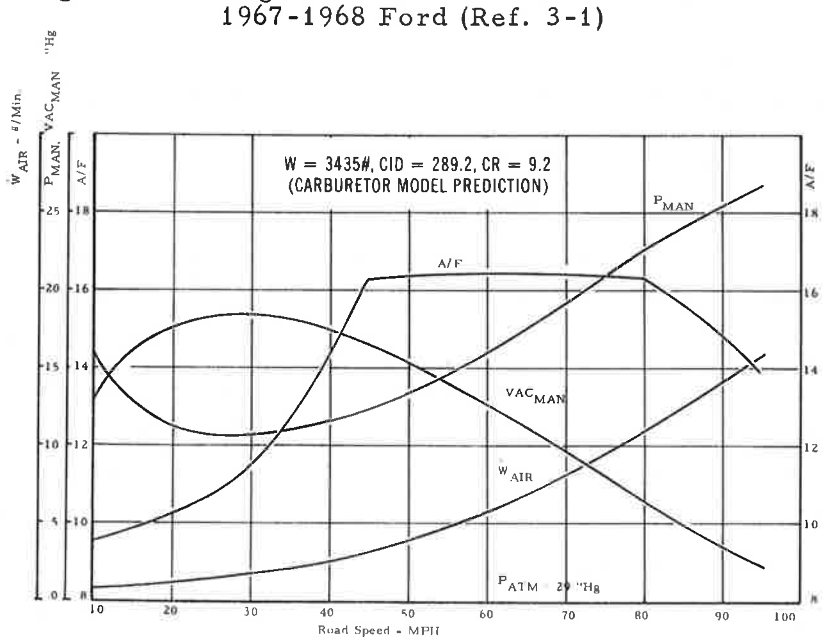


Figure 3-2. Air Characteristics for 1967-1968 Ford (Ref. 3-1)

The brake horsepower parameter (bhp) displays the sum total of power requirements needed to overcome road and air resistance and to operate engine accessories such as the alternator, water pump, and fan. The steep rise in the bhp characteristic at high road speed is due primarily to the effects of air drag, which varies as the square of the speed of the automobile.

The specific fuel consumption parameter (sfc) is a direct measure of fuel flow rate per unit brake horsepower output of the engine, and is therefore an inverse indicator of engine efficiency. As indicated by the sfc characteristic, the engine efficiency is relatively poor (high sfc) in the low speed range, tends to improve with increasing speed and engine power output, and reaches an optimum or lowest value of sfc at a relatively high speed condition.

The shape of the sfc curve, combined with the bhp characteristic, establishes the trends shown in the miles-per-gallon (mpg) of fuel economy characteristic. At low road speeds, fuel economy is poor because of the low engine efficiency (high sfc). As speed and engine load increase, the fuel economy improves, reaches a peak, and then decays. The decay is due to the rapidly increasing bhp (and corresponding high fuel flow) required to overcome air resistance at high speeds. The speed at which the miles-per-gallon characteristic peaks, here shown at 45 miles per hour, varies among different automobiles and may range from about 35 to 45 miles per hour.

Typical engine air characteristics at steady-state road-load conditions are shown in Figure 3-2. The air-fuel characteristic reflects three basic regimes of engine operation. At low speeds and loads, the engine demands a fuel-rich charge for satisfactory performance; this requirement is met by designing the carburetor to deliver the relatively rich mixtures (low values of air-fuel) indicated in the speed range below about 40 miles per hour. At intermediate speeds, maximum economy is the objective, and the flat air-fuel profile at the level of about 16 is designed for this purpose. At high speed or load, maximum power is sought, and the fuel charge is correspondingly enriched, as indicated in the curve starting at about 80 miles per hour. Power enrichment is triggered by manifold vacuums or throttle positions typical of high power or acceleration demand. Continued or repeated operation in this regime can significantly reduce overall road fuel economy.

The weight flow of air characteristic shows a rising trend that reflects the increase in total air-fuel charge needed to generate greater bhp output at higher speeds. In correspondence with the increased flow of air, the manifold pressure characteristic shows a generally increasing trend with speed, approaching atmospheric pressure at peak road speed or wide-open throttle conditions. The manifold vacuum characteristic, a mirror image of the pressure curve, shows that, at the 45 mile-per-hour peak fuel economy speed indicated in Figure 3-1, the manifold vacuum level is about 18 inches of mercury. At higher speeds, the vacuum continues to decay as engine power increases with throttle opening. The point of power enrichment of the air-fuel mixture may be seen to correspond to a manifold vacuum of about 7 inches.

3.1.2 Part-Throttle or Transient Characteristics

The effects of transient or part-throttle operating conditions on several of the important variables displayed in the steady-state case are illustrated in Figure 3-3 for the same 1967-1968 Ford vehicle, showing relationships between air flow, manifold pressure, engine revolutions per minute, and throttle angle. Superimposed on this map is the locus of values for manifold pressure and air flow at steady-state road-load cruise conditions. The region of increasing engine power output or acceleration from steady-state speed lies to the right of the road-load curve in the direction of increasing throttle angle position, increasing air flow, and increasing manifold pressure (decreasing engine vacuum). Deceleration or decaying power output lies to the left of the curve, in the direction of decreasing air flow and decreasing manifold pressure (increasing vacuum). In a typical braking deceleration, where the engine is motored, manifold pressure will quickly drop to 3 to 7 inches of mercury; that is, manifold vacuum will increase to a level of 22 to 26 inches, depending on the engine (or road) speed at the start of deceleration.

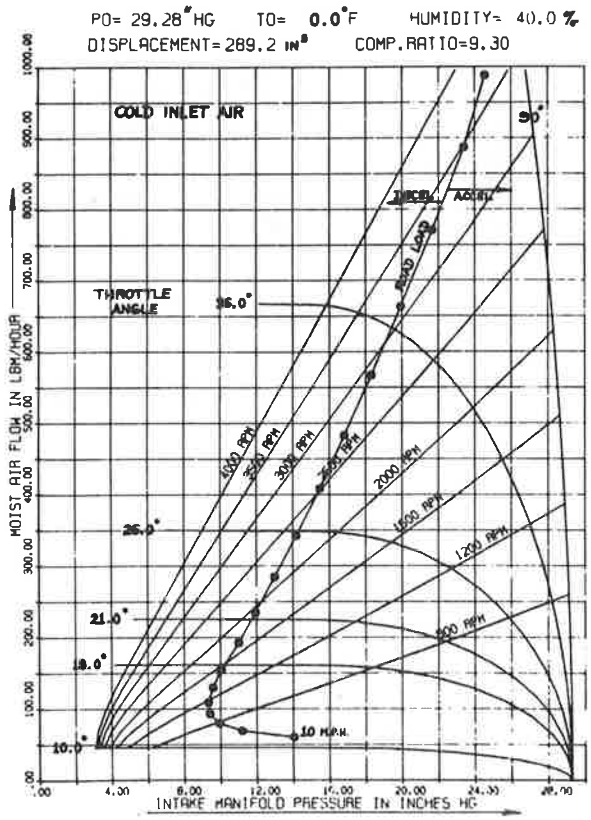


Figure 3-3. Carburetor-Engine-Vehicle Operating Map (Ref. 3-1)

Characteristics of the fuel-air mixture (the inverse of the air-fuel parameter used in the road-load cruise curve) under part-load conditions are given in Figure 3-4, showing steady flow mixtures over a wide range of speed and load. The abrupt increase in fuel-air ratio shown for several selected engine speeds corresponds to the opening point of the carburetor power enrichment valve. The condition for initiation of power enrichment as sensed using engine vacuum can be identified by correlating the air flow and engine revolution-per-minute data shown here with similar data provided in Figure 3-3. This point is 7 inches of vacuum, corresponding to the value previously derived from examination of the road-load cruise curves.

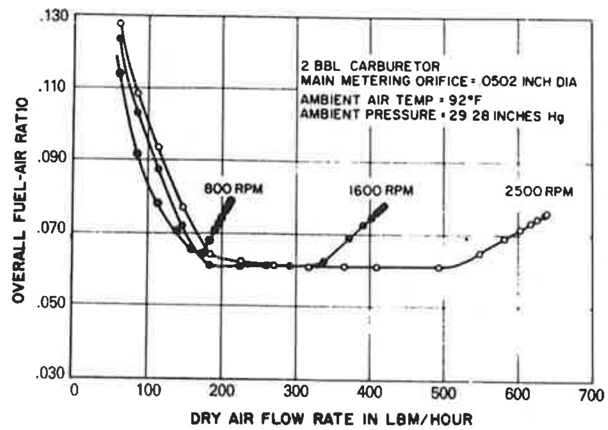


Figure 3-4. Computed Carburetor Metering Curve (Ref. 3-1)

3.1.3 Sensible Engine Parameters

Measurements of engine characteristics and performance that provide some indication of fuel economy and thus could be used as the sensible parameter in a driver aid include manifold vacuum, throttle position, engine air flow, and exhaust gas temperature. These are discussed in this section with respect to their sensitivity to changes in the rate of fuel consumption and the consistency of this indication over the broad range of engine operating conditions. How these measurements are applied in the different driver aid devices is discussed in Section 4.

3.1.3.1 Manifold Vacuum

Manifold vacuum is the difference in pressure within the intake manifold from that of the surrounding atmosphere. At wide-open throttle, this difference approaches zero. In part-throttle operation at moderate level road speeds, this pressure difference, which varies with power requirements, typically falls within the range of 8 to 18 inches of mercury.

Shown in Figure 3-5 is a plot showing the relationship between manifold vacuum and fuel flow rate for a typical engine operating over a range of

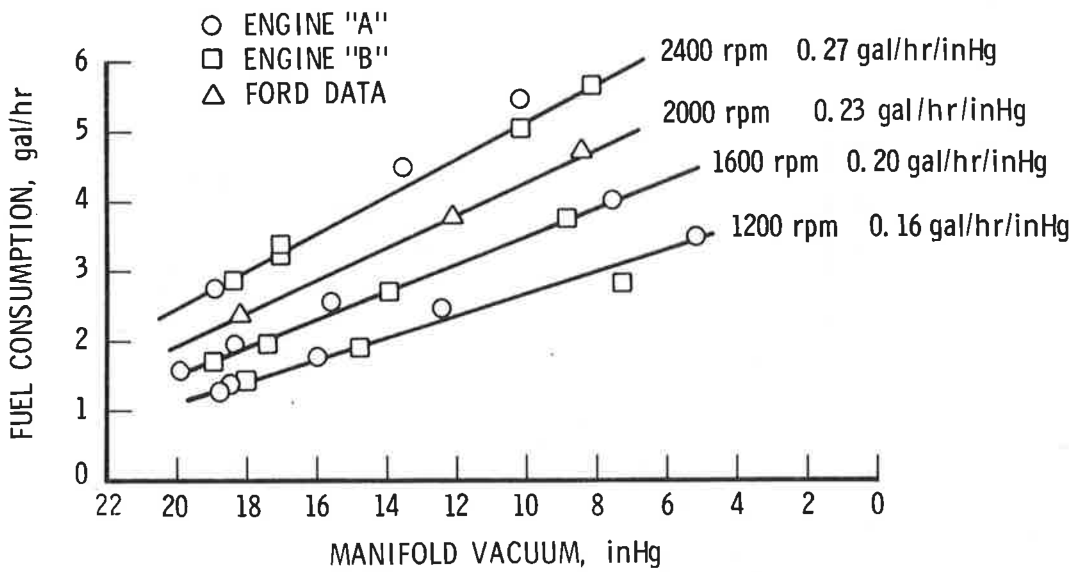


Figure 3-5. Fuel Consumption as a Function of Manifold Vacuum (Refs. 3-1a, 3-1b)

speed conditions. From this figure, it can be seen that manifold vacuum is quite sensitive to changes in the rate of fuel consumption and that its variation is reasonably linear for each of the engine revolution-per-minute conditions. As shown by the correlations that are noted on the figure, the sensitivity of this measure is variable as a function of engine revolutions per minute. Since manifold vacuum is a differential pressure measurement, its indication of the absolute rate of fuel consumption will vary with the change in the surrounding atmospheric pressure at different altitude conditions.

3.1.3.2 Throttle Position

Illustrated in Figure 3-6 is the variability in fuel consumption rate as a function of throttle position (percent of angle at wide-open throttle) for a range of engine operating speeds. In the somewhat compressed scale presentation that is shown in the top half of this figure, it can be seen that, at the more open throttle positions, the change in fuel consumption rate is quite

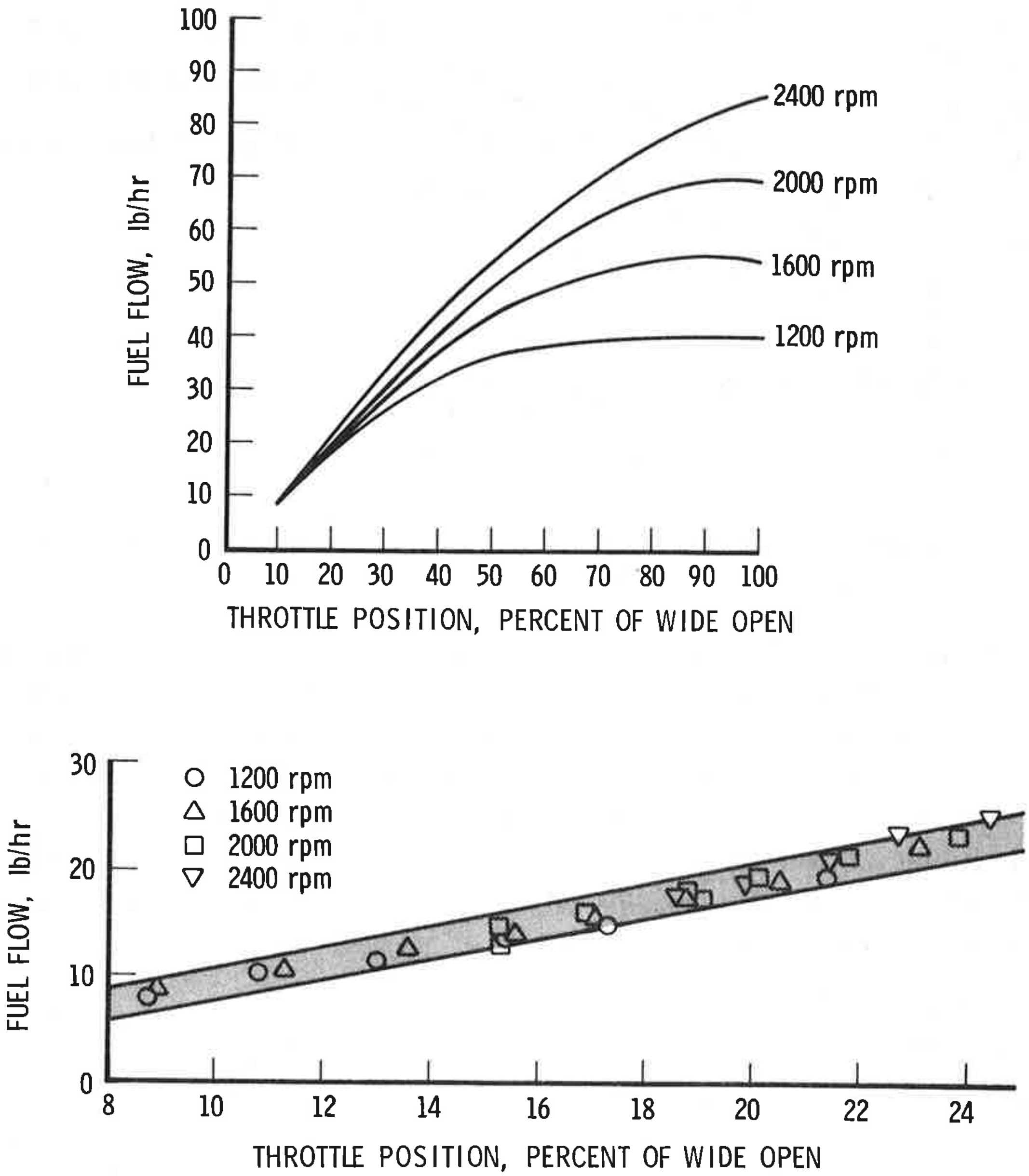


Figure 3-6. Throttle Characteristics (Ref. 3-1c)

sensitive to differences in engine revolutions per minute. In order to illustrate a fundamental difference in characteristic that exists at the more closed throttle position, the engine rpm data points are plotted against a more expanded scale in the bottom half of the figure. Here, it can be seen that the change in fuel consumption rate is relatively insensitive to differences in engine revolutions per minute.

This difference in characteristic results from the transition from sonic to subsonic flow conditions across the throttle plate that occurs at a throttle opening of about 25 percent. At lower throttle positions a sonic flow condition prevails that causes the air flow to be constant for a given opening and, thus, results in a reasonably constant fuel flow rate since air-fuel mixture is held relatively constant.

It is of some interest to note that, at a 25-percent throttle opening, the engine delivers about 50 percent of its rated power. Since typical driving conditions usually require less than this amount of power, a direct measurement of throttle position could provide a convenient and reasonably accurate measurement of fuel consumption.

3.1.3.3 Engine Air Flow

It is implicit that engine air flow must be highly correlated with changes in fuel flow rate since it is the air flow in the carburetor venturi that controls the fuel flow rate. As shown in Figure 3-7, this correlation is designed to be fairly consistent over most of the range of engine operating conditions. This design is a result of the desirability from a fuel economy standpoint of operating at the leanest possible mixture ratio that provides good performance, usually a constant air-fuel ratio value of about 16:1. The nonlinearity at the very low and high air flow rates reflect the mixture enrichment needed to obtain maximum power.

3.1.3.4 Engine Exhaust Temperature

Engine exhaust temperature is a function of many interacting variables. Thus, by itself it would not be expected to show a consistent variation

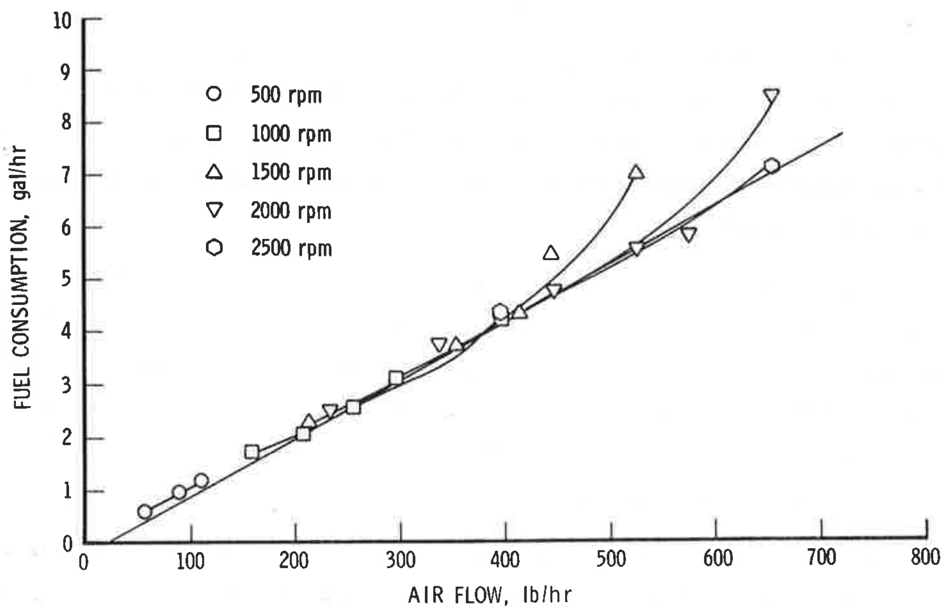


Figure 3-7. Fuel Consumption as a Function of Air Flow (Ref. 3-1b)

when viewed with respect to a single parameter, which is evident as illustrated in Figure 3-8. The data points that are plotted in this figure are coded to show the effects of variable power for constant engine speed conditions. Because of the wide scatter of this data, it may be difficult to correlate this parameter accurately with changes in the rate of fuel consumption.

3.2 IMPACT OF VEHICLE ACCELERATION RATE

The difference between the level-road speed engine torque requirements and the total engine torque possible is available for acceleration. This large excess torque and the corresponding power that is usable at the option of the driver are generally considered to be significant factors in establishing the difference in fuel economy achieved among different drivers.

From a search of the literature and discussions with engineering personnel of the major automobile manufacturers, it was found that the subject of fuel economy effects resulting from differences in driver acceleration

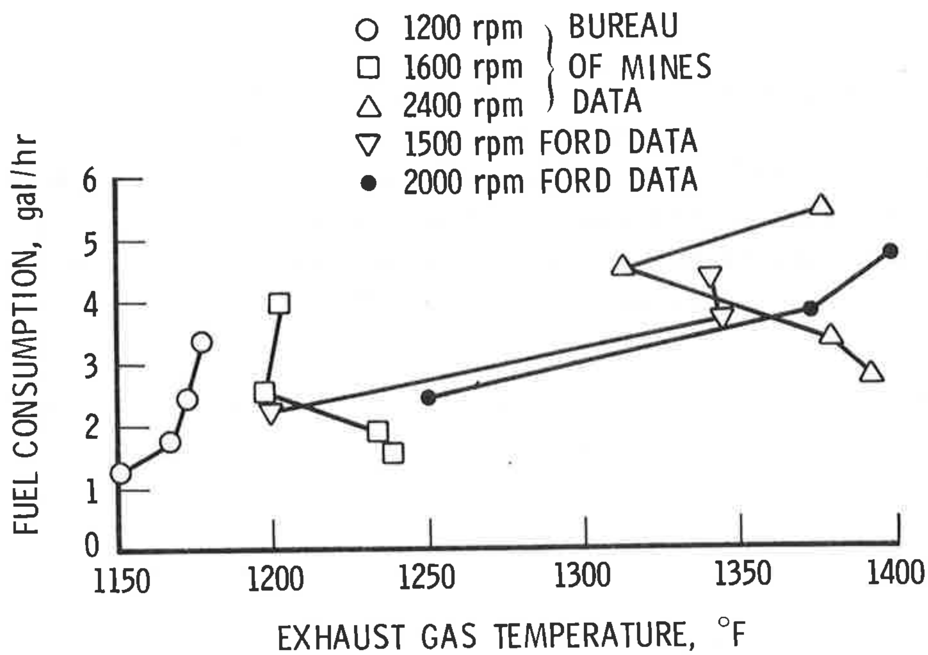


Figure 3-8. Fuel Consumption as a Function of Exhaust Gas Temperature (Refs. 3-1a, 3-1b)

practices has not been extensively explored and, thus, the available data characterizing these effects are meager. While it is not within the scope of this study to perform the complex analyses required to quantify these factors accurately, it is nevertheless possible to illuminate some elements of the problem and to provide some degree of quantification in this area.

Under the conditions of acceleration, one or more of several effects may influence the efficiency of fuel usage and therefore may impact road fuel economy. One of these effects is related to the operation of the carburetor accelerator pump, another is associated with the activation of the carburetor power enrichment system, and a third effect derives from a change in engine efficiency at the different operating conditions produced by the dynamics of the acceleration maneuver.

Accelerator pump effects are small and frequently ignored in simulating engine performance since the full stroke delivery of a typical pump is only 2 cubic centimeters or 0.00054 gallons; the function of the device is simply to offset a temporary leanness in the air-fuel mixture produced when the throttle is suddenly opened. The carburetor power enrichment system operates in response to heavy power demand typically associated with engine vacuum levels near 7 inches of mercury, as discussed earlier. The fuel consumption increase may be 20 percent or higher over the duration of the enrichment transient.

In contrast to the accelerator pump and power enrichment effects, which tend to increase fuel consumption and decrease fuel economy relative to steady-state road-load performance, acceleration effects on engine operation outside of the power enrichment regime may either increase or decrease fuel economy, depending upon the specific performance characteristics of the engine and the region of the engine operating map in which the acceleration takes place. It may be shown that, at low power and moderate engine speed, a light acceleration produces a gain in fuel economy compared to steady-state cruise at the same average speed.

Aside from the efficiency of the acceleration maneuver taken by itself, the effects of acceleration considered in the context of a complete trip duty cycle also bear examination. An example of how duty cycle may govern the effect of acceleration on fuel economy for a given trip profile is shown in Figure 3-9. Here are plotted the calculated results for speed, cumulative fuel consumption, and cumulative fuel economy versus distance traveled for a small automobile with manual transmission accelerating through gears from a standing start to 40 mph steady-state cruise speed. These results are based on the assumption of constant acceleration and were derived from a progressive integration of instantaneous fuel consumption rates obtained from the engine performance map and calculated power for a 1970 115-CID Toyota. The 40-mph speed, it is to be noted, is favorable for good fuel economy. Results for three constant accelerations are shown: a light acceleration of 0.05 g, corresponding to 54 seconds for 0 to 60 mph performance, a moderate acceleration of 0.1 g, corresponding to 27 seconds for 0 to 60 mph

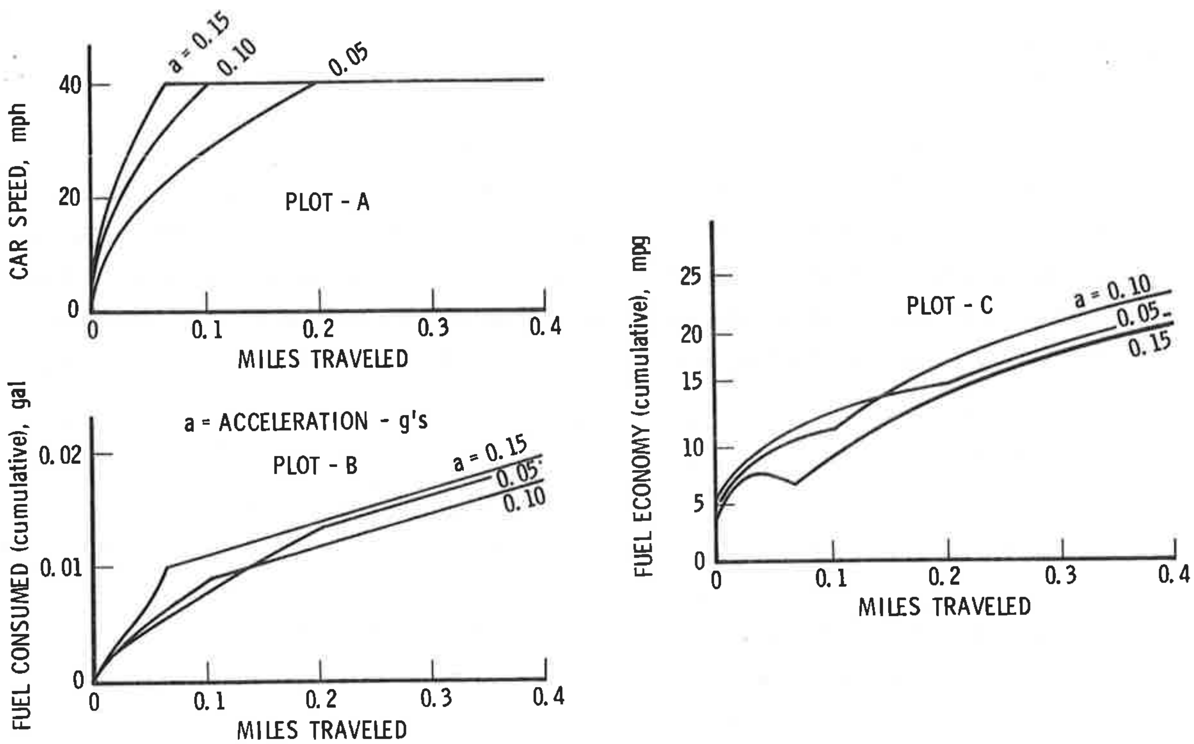


Figure 3-9. Combined Acceleration/Cruise Effects on Trip Fuel Economy (0.4-Mile Trip, 40 mph Cruise Speed)

performance, and a "brisk" acceleration of 0.15 g corresponding to 18 seconds for 0 to 60 mph performance. The 0.15 g case represents near-maximum capability for this vehicle and involves carburetor power enrichment throughout much of the engine speed and load range.

Referring to plot b of Figure 3-9, and comparing first the 0.1 g and 0.05 g accelerations, one can see that the fuel consumed is initially greater for the more severe 0.1 g acceleration. However, since the favorable 40 mph cruise speed condition is reached in shorter time and distance, the cumulative consumption charcteristic levels out and crosses under the curve for 0.05 g. For the 0.15 g acceleration, the same general shape characteristics are noted, except that in this case the relatively high fuel consumption penalty in the acceleration transient raises and maintains the general level of the cumulative consumption curve close to but slightly above the 0.05 g characteristic. These effects are expressed in terms of cumulative fuel economy (total miles per total gallons) in plot c. Here, it is shown that, while the 0.1 g acceleration transient yields a poorer cumulative fuel economy (about 11 mpg) than the 0.05 g acceleration transient (about 15 mpg), the 0.1 g trip profile attains a slightly higher overall trip fuel economy by about 8 percent. The 0.15 g case shows about the same fuel economy result as 0.05 g, thereby indicating a loss in fuel economy relative to the 0.1 g acceleration condition.

It should be noted that, if the inefficiencies of an automatic transmission were to be incorporated in the above calculation, the effect would be to bring the results for the 0.05 and 0.1 g trip profiles closer together. Likewise, if the selected cruise speed condition were taken not at 40 mph but at 50 mph, a less favorable speed with respect to cruise fuel consumption, the 0.05 and 0.1 g results would have been closer than 8 percent and, indeed, at still higher speeds the trend of fuel economy with acceleration might have shown a reversal of effects between these two cases.

The significance of this demonstration is to highlight the fact that the issue of acceleration inefficiency taken alone may not be in itself an overriding or dominant factor in determining road fuel economy. Rather, trip driving specifics involving excessive speeds in traffic situations that require heavy braking and consequent loss (and need for recovery) of vehicle kinetic energy may be the significant parameters. Additionally, since rapid or overextended acceleration in many cases may lead to overspeed, it is possible that the excessive acceleration and excessive braking driver attributes are correlated. The effect of driver technique was confirmed by an informal experiment conducted by the Los Angeles Police Department with an intermediate-size patrol car equipped with a 401-cubic-inch engine and driven over a 100-mile city test segment (Ref. 3-2). The car was equipped with an intake manifold vacuum control device to maintain fixed acceleration levels. The acceleration level was constrained to three different conditions and the following results were obtained.

Vacuum Level, in.	Acceleration Level	Fuel Economy, mpg	Relative Fuel Economy
10	Mild	14.7	1.176
5	Normal traffic flow	12.5	1.0
0	Maximum	8.5	0.68

The penalty for "flooring" the gas pedal to accelerate was a 32 percent reduction in fuel economy. Except for emergency situations, this procedure should obviously be avoided. The gain in fuel economy caused by reducing the acceleration level to the "mild" condition was nearly 18 percent. An increase of this magnitude, as noted above, would not be anticipated based on considerations of acceleration rate and cruising speed alone. It is likely, therefore, that the gain at the lower acceleration level was a cumulative one representing fewer tendencies to over-accelerate and then have to over-decelerate and brake excessively under the stop-and-go traffic conditions of the 100-mile city test segment.

In view of these considerations, the admonition to drive as if an egg were placed between the driver's foot and the accelerator pedal might better be stated with the egg on the brake. These and other fuel economy factors under the control of the driver are further discussed below in Section 3.3.

3.3 FACTORS UNDER CONTROL OF THE DRIVER

The car driver is an integral part of the automobile control system. Aside from directional control (steering wheel), he provides the sensing and control logic for and the inputs to the throttle and brake pedals; i.e., he controls the rate of acceleration, steady-state speed levels, deceleration rate, and stoppage of the vehicle.

As noted in Sections 3.1, 3.2, and Appendix A, for a given size, type, and weight vehicle, the fuel economy obtained is a function of the following:

a. Steady-state speed at cruising conditions

b. Rate of acceleration and deceleration under stop-and-go driving conditions

c. Ambient temperature and cold-start conditions

d. Number of stops per mile for cyclic driving conditions

Assuming, for purposes of discussion, that the driver is constrained to a given set of cyclic driving conditions (e.g., limited to a given route to travel to and from work), the driver's principal control, relative to fuel economy, rests in (1) his ability to select an acceleration level and a steady-state cruising speed that are appropriate for the length of the trip segment being made, and (2) his ability to decelerate smoothly without excessive engine deceleration requirements or braking. It is to these human control functions that the majority of driver aid devices is aimed, utilizing one or more of the operating parameters described in Section 3.1 as the sensing basis.

On an overall basis, of course, the driver has other discretionary options that can aid in improving fuel economy. Many articles have been written describing good driving techniques in terms the average driver can understand and implement. Table 3-1 summarizes the basic elements from three such articles. As can be noted, aside from predriving planning, major emphasis is directed toward (1) avoiding excessive vehicle accelerations, (2) conserving vehicle momentum by avoiding excessive deceleration and braking, (3) cruising at moderate, economical speeds, and (4) avoiding prolonged engine idling.

3.4 FUEL ECONOMY TEST RESULTS

The principal function of a fuel economy driver aid device is to furnish information to the driver that will enable him to drive more economically. The implied assumption behind the previous statement is that driver habits do have an appreciable effect on fuel economy and that driving habits can be improved. This section is a brief summary of a number of tests where data were obtained on the effect of driving habits on fuel economy.

The Shell Oil Company performed a test where 23 untutored drivers were selected to drive a test course that included both town and freeway driving (Ref. 3-6). The car used for the test was a 1972 Chevrolet with a 350-CID engine. The test car was equipped with a meter to measure gasoline consumption to 1/1000 of a gallon. Before the first test the car was detuned to simulate a car that was not maintained well. The drivers all drove the

TABLE 3-1. GOOD DRIVING TECHNIQUES FOR IMPROVING FUEL ECONOMY

Article	Technique
American Automobile Association (Ref. 3-3)	o Driving Planning / Use more economical car owned for bulk of driving, particularly for commuting to and from work or local stop-and-go driving. / Plan routes to avoid extra-long traffic lights and congested streets; use less-traveled roads and free-flowing highways; avoid rush hours and peak traffic times. / On long trips, start early in morning to avoid traffic and minimize use of air conditioner. / Keep baggage to a minimum and avoid packing on a roof rack. o Driving Execution / Avoid extended warmups. / Accelerate gently and drive slowly for a mile or so after car is drivable. / Avoid unnecessary idling. / Don't rev up the engine prior to shut-off. / Look well ahead to spot slowdowns and red lights; keep a good space in front so you can adjust speed gradually; release accelerator early and brake gradually when stopping. / Use smooth, steady accelerator pressure for cruising; use gradual acceleration and braking. / Travel at moderate speeds (under 55 mph). / When approaching a hill, build up speed early to avoid a hard acceleration on the upgrade.
Motor Vehicle Manufacturers' Association (Ref. 3-4)	o Avoid "jack rabbit" starts and "hotrod" driving. o Avoid unnecessary acceleration and unnecessary braking. o Do not drive faster than necessary on highways. o Maintain a steady speed as long as traffic conditions permit.

TABLE 3-1. GOOD DRIVING TECHNIQUES FOR IMPROVING FUEL ECONOMY (Continued)

Article	Technique
D. L. Berry, Shell Oil Company (Ref. 3-5)	o Use moderate speeds (best cruise speed is 30-40 mph). o Drive at smooth, steady pace (when traffic permits). o Accelerate slowly, allow automatic transmission to upshift. o Anticipate stops, minimize braking. o Prolonged idle for warmup not necessary. o Limit extensive idling, stop engine. o Be sure parking brake is fully released. o Minimize electrical loads and use of air conditioner. o Consolidate short trips, plan routes in advance, avoid heavy traffic.

22.3-mile test course with this car. Before the next test, and unknown to the drivers, the car was tuned to manufacturer's specification and steel-belted radial tires substituted for four-ply polyester tires. The drivers again drove the test course with the tuned car. For the first two tests, the real purpose of the tests were not disclosed to the drivers. They were asked to drive the course as they normally would. For the third test, the drivers were all told about the purpose of the test. During the third test they were accompanied and coached by an expert in gas-saving techniques. Compared to the first test with the untuned car, the drivers in the second test with the tuned car achieved a 14.6 percent average gasoline mileage improvement. For the third test where they were coached in fuel economy techniques, the drivers achieved a 8.9 percent average gasoline mileage improvement over the second test. The improvements for the third test varied from 0.3 to 21.8 percent.

The Mobil Oil Corporation conducted a test to determine if economy driving techniques can be self-taught (Ref. 3-7). Twenty employees not associated with automotive-oriented areas were selected. They were asked to drive an 18-mile test course in their normal manner. The car used was a 1973 Chevrolet with a 350-CID engine and automatic transmission. The course provided a 50-50 mix of urban and suburban driving. After the first test the purpose of the test was described to the participants and economy driving manuals distributed to them. They were asked to read the manuals, but they did not receive any other instructions in driving techniques. Several days later the drivers again drove the test course. The drivers recorded a 15 percent average improvement in miles per gallon for the second test. The improvement varied from 4 to 26 percent. A third test was conducted where eight participants who had achieved high, medium, and low levels of gas mileage improvements were asked to drive the test course using a vacuum gage (a Stewart-Warner Motor Minder). They achieved an additional gas mileage improvement of only 1 percent over the second test.

The Automobile Club of Michigan conducted a test to determine the gasoline mileage loss when a car is operated by a bad driver in comparison with a good driver (Ref. 3-8). They used a 1971 Chevrolet Impala with a 350-CID engine driven over a 22.8-mile commuter route. The good driving techniques included smooth acceleration, travelling at an even rate of speed, and never using the brakes more than necessary. To demonstrate bad driving habits, the test driver made "jack-rabbit starts, rapid stops, weaved in and out of traffic, and several times accelerated to the point where he had to apply brakes to avoid hitting the car in front of him." With the good driving habits the test driver achieved 14.4 miles per gallon, while with the bad driving habits he obtained 8.1 miles per gallon for a 44 percent loss in fuel economy. In another phase of the test on a 10-mile expressway route, the driver recorded 13.9 miles per gallon for good driving habits and 10.7 miles per gallon for poor driving habits, a decrease of 23 percent.

The Automobile Club of Southern California conducted a test to determine the influence of various factors such as tire pressure, air conditioning, and vehicle weight on fuel consumption (Ref. 3-9). In one of the tests, they determined the effect of varying rates of acceleration on fuel economy. They used 20 vehicles consisting of small, medium, and large cars, all but one with automatic transmissions. The acceleration test consisted of running the car a quarter of a mile from a standing start. Three rates of acceleration were used: "easy," "moderate," and "heavy." The rates were subjectively determined by the driver and were not closely controlled or measured. For all tests, the terminal speed of the car was 40 miles per hour. The test results showed that the "moderate" acceleration used 12.4 percent more fuel than the "easy" acceleration, and that the "heavy" acceleration used 27.7 percent more fuel than "easy" acceleration.

The Douglas Aircraft Company of Long Beach, California, has established a vehicle energy conservation program that includes improved maintenance procedures, vehicle modifications, and a driver training program for all of their fleet drivers (Ref. 3-10). The driver training program consists of instruction in driving techniques in order to achieve better fuel economy as well as training in special vehicles equipped with various types of driver aids such as a miles-per-gallon gage, vacuum gage, and exhaust temperature pyrometer. To determine the effectiveness of driver training, they selected a test group of 15 drivers to drive a course of approximately 25 miles in standard vehicles. The drivers then received the training course and drove the test course again in a driver training vehicle equipped with the driver aids. Fuel economy improved by 22.1 percent. Douglas Aircraft claims an overall 19 percent improvement in fuel economy for their entire fleet of vehicles in actual operational use as a result of their energy conservation program.

The DOT Transportation Systems Center (TSC) and the National Highway Traffic Safety Administration (NHTSA) conducted a joint pilot test program to determine the impact of driver training on fuel economy (Ref. 3-11). The program involved 20 drivers: 10 with no training and 10 with one hour of training. A single car was used over a 9-mile test route. An approximately 10 percent improvement in fuel economy was observed for the class of drivers with the one hour of training.

Table 3-2 summarizes the foregoing programs and results. The results of the Shell, Mobil, and TSC/NHTSA fuel economy tests indicated that the driver can increase his fuel economy by about 9 percent to 15 percent by improving his driving habits. The Automobile Club of Michigan test in general confirmed these results but showed considerably larger gains because the driver purposely tried to drive poorly. Therefore, the Automobile Club of Michigan economy losses of 44 percent on a commuter route and 23 percent at freeway speeds can perhaps be considered as upper limits. It is important to note that the Shell and Mobil tests were of very short duration. The drivers were conscious of the tests and applied themselves toward improving their fuel economy. What is not known is if the same drivers over a longer period of time fell back into their old driving habits.

The Mobil test indicated that the use of a vacuum gage resulted in only a one percent additional improvement in fuel economy. This finding may indicate that the most important function of a fuel economy driver aid is to remind the driver when he starts to fall back into his old driving habits.

The Automobile Club of Southern California acceleration tests indicated that the lower the acceleration the better the fuel economy.

The Douglas Aircraft Company driver training program indicated that substantial improvements in fuel economy can be achieved by fleet drivers. However, as pointed out in Section 6, motivation and monitoring the driver's performance are necessary in order to continue to achieve these results over a long time period.

Although the data base is quite limited, these tests indicate a potential for 10 to 15 percent improvement in fuel economy because of fuel-efficient driving habits. Thus, the interest in driver aids is twofold: first, as a device to aid in driver training, and second, as an aid to remind a trained driver when he tends to return to poor driving habits.

TABLE 3-2. FUEL ECONOMY VERSUS DRIVING HABITS—TEST RESULTS

Company/ Agency	Purpose of Test	Results of Test
Shell Oil Company	Improvement due to coaching in gas saving techniques (23 drivers, 1 car, 22.3-mile course)	8.9% improvement over well-tuned car with radials
Auto Club of Southern California	Determine effect of acceleration levels (1 driver, 20 cars, 1/4 mile, standing start to 40-mph speed)	12.4% loss due to "moderate" acceleration 27.2% loss due to "heavy" acceleration
Mobil Oil Corporation	Improvement due to reading driving instruction manual (20 drivers, 1 car, 18-mile course)	15% improvement
	Effect of using vacuum gage after reading manual (8 drivers, 1 car, 18-mile course)	1% improvement over 15% achieved by reading only
Auto Club of Michigan	Determine effect of bad driving habits as compared to good driving techniques (22.8-mile commuter route, 10-mile expressway route, 1 car)	44% loss due to bad driving on commuter route 23% loss due to bad driving on expressway route
Douglas Aircraft Company	Determine impact of driver training program on fleet drivers. Instruction in driving techniques and training in vehicles equipped with MPG meter, vacuum gage, pyrometer (15-driver test group)	22.1% improvement due to training program with 15 drivers
TSC/NHTSA	Pilot test to determine impact of training (10 drivers with no training, 10 drivers with 1 hour training, 9-mile route, 1 car)	~10% improvement for driver with 1 hour of training

4. TYPES OF DEVICES AND THEIR GENERAL OPERATING PRINCIPLES

A number of different types or classes of devices are being offered or could be made available to the general public as driver aids to assist in reducing the amount of fuel consumed during normal driving operations. They can be generally categorized as follows:

a. Manifold vacuum devices
b. Engine and vehicle speed devices
c. Fuel flow devices
d. Air flow rate devices
e. Miles-per-gallon devices
f. Air-fuel ratio devices
g. Exhaust manifold temperature devices
h. Throttle position devices
i. Accelerator pedal feedback devices
j. Automatic cruise control devices
k. Various types of displays

Within each of these general classes of driver aid devices, there are usually several manufacturers offering a specific version for sale; this is particularly true for the manifold vacuum device class. In addition to the device manufacturers (including the automobile manufacturers), there are a number of government and industrial organizations that have instituted testing and evaluation efforts in the interest of improving fuel economy.

This section discusses the general operating principles of these types of devices and provides a brief description of specific devices within each category, along with their features and applicable test data where available.

4.1 MANIFOLD VACUUM DEVICES

4.1.1 Operating Principles

A manifold vacuum device senses and measures the intake manifold vacuum and provides some form of visual or audible readout to the car driver. During the intake stroke the piston draws a fresh charge of air and fuel into the cylinder. Because of the restriction caused principally by the throttle but also by the carburetor venturi and the intake manifold, there is always a vacuum in the intake manifold, i.e., the pressure is always below atmospheric pressure. The lowest manifold vacuum occurs when the throttle is wide open, and the highest occurs when the throttle is nearly closed (even higher vacuum readings occur when the car is decelerating and the throttle nearly closed). Since the throttle position is related to engine load or horsepower, the intake manifold vacuum is a measure of the load on the engine. The amount of fuel being used is also directly related to the load on the engine, and therefore the intake manifold vacuum is related to the amount of fuel being consumed. As a result, it has been recognized for many years (principally by those involved in automobile performance testing, racing, or economy runs) that gages which measure the intake manifold vacuum can be useful for monitoring engine operating conditions that relate to fuel consumption.

The vacuum gage is simple, inexpensive, and easy to install. Installation is accomplished by connecting a vacuum hose directly to the intake manifold or cutting a convenient vacuum line and inserting a tee. The generally accepted method of using a vacuum gage to minimize fuel consumption is to drive so that the manifold vacuum is at the highest possible value. For a typical engine, the intake manifold vacuum will be about 18 to 20 inches of mercury (in. Hg) at idle, about 15 at cruise, and 5 to 10 while climbing a moderate hill. Moderate accelerations can be accomplished at 10 in. Hg; for climbing a steep hill, very rapid accelerations, and other high load conditions, the engine vacuum can fall to near zero.

At steady speeds on a level road, the vacuum reading on a typical automobile will reach a peak somewhere between about 30 and 40 miles per hour. Figure 3-2 showed the vacuum characteristic for a full-sized car in high gear. The average driver may have some difficulty in observing the vacuum level characteristic illustrated in Figure 3-2 because the vacuum level is very sensitive to small changes in accelerator pressure and in the grade of the road. Unless the automobile is being driven at a steady speed on a level road, the vacuum reading will continually fluctuate. Also, a shift of the transmission to a different gear ratio will also affect vacuum level.

A vacuum gage will indicate that the more moderate the acceleration the higher will be the vacuum level. A driver will also notice that when he encounters a hill, his vacuum level will drop if he climbs the hill at constant speeds, and will drop further if he attempts to accelerate up the hill. On the other hand, the vacuum level will not decrease as much if he decelerates somewhat when climbing the hill. Thus, the principal information gained from using a vacuum gage is that, to maintain high engine vacuum, one should accelerate the car slowly, and if possible, one should decelerate somewhat going up hills. Since the vacuum gage is also quite sensitive to moderate accelerations and decelerations, it also indicates to the driver if he is maintaining a steady foot on the accelerator.

A basic shortcoming of the vacuum gage is that it is an indicator of engine load and thus fuel consumption and not fuel economy (miles per gallon). A typical automobile will achieve best fuel economy in terms of miles per gallon at about 35 to 45 miles per hour. The fuel economy at very low speeds, e.g., 20 miles per hour, is generally poor. On the other hand, since the engine load at 20 miles per hour is very small, the vacuum gage will display a relatively high reading, which would lead the uniformed driver to believe he is achieving high miles per gallon at this condition. Another problem with the vacuum gage is that it measures engine vacuum relative to ambient atmospheric pressure. Therefore, the readings are affected by atmospheric pressure changes and consequently by altitude changes. At high altitude the vacuum readings can be considerably lower than at sea level. For consistent driving at a given altitude, this characteristic may not significantly impact the utility of the vacuum gage, since it serves simply as an indicator of relative power output level in different driving modes. Some adjustment in the interpretation of gage readings may, however, be required for the driver changing his customary operating altitude.

A side benefit of the vacuum gage is that it is also useful for diagnosing certain engine problems. Problems such as sticking valves, weak valve springs, burned valves, or an improperly operating choke, will cause low or oscillatory vacuum readings. Figure 4-1 depicts how a car's condition can be interpreted from a vacuum gage dial reading.

4.1.2 Specific Manifold Vacuum Devices

A large number of vacuum gages for automotive use are available on the market. Among the manufacturers of vacuum gages are Rite Autotronics Corp., Los Angeles, California; Stewart-Warner Corp., Chicago, Illinois; Sun Electric Company, Chicago, Illinois; and Teleflex, Inc., Limerick, Pennsylvania. Most of the gages are quite similar, being basically diaphragm devices. One side of the diaphragm is exposed to atmospheric pressure, and the other to engine intake manifold pressure. Changes in the pressure cause the diaphragm to move. Through suitable mechanical linkage the movement of the diaphragm operates a dial indicator needle. Most gages have a range from 0 to 30 in. Hg of manifold vacuum. Many of the gages show numerical readings on the face. Many also have colored zones corresponding to poor, fair, and good economy; some incorporate and designate a deceleration range. Typical color formats used are red for the range from 0 to 5 in. Hg, yellow from 5 to 10, green from 10 to 22, and blue above 22. Many gages have no numerical calibration at all, and the driver must rely on the colored zones for information.

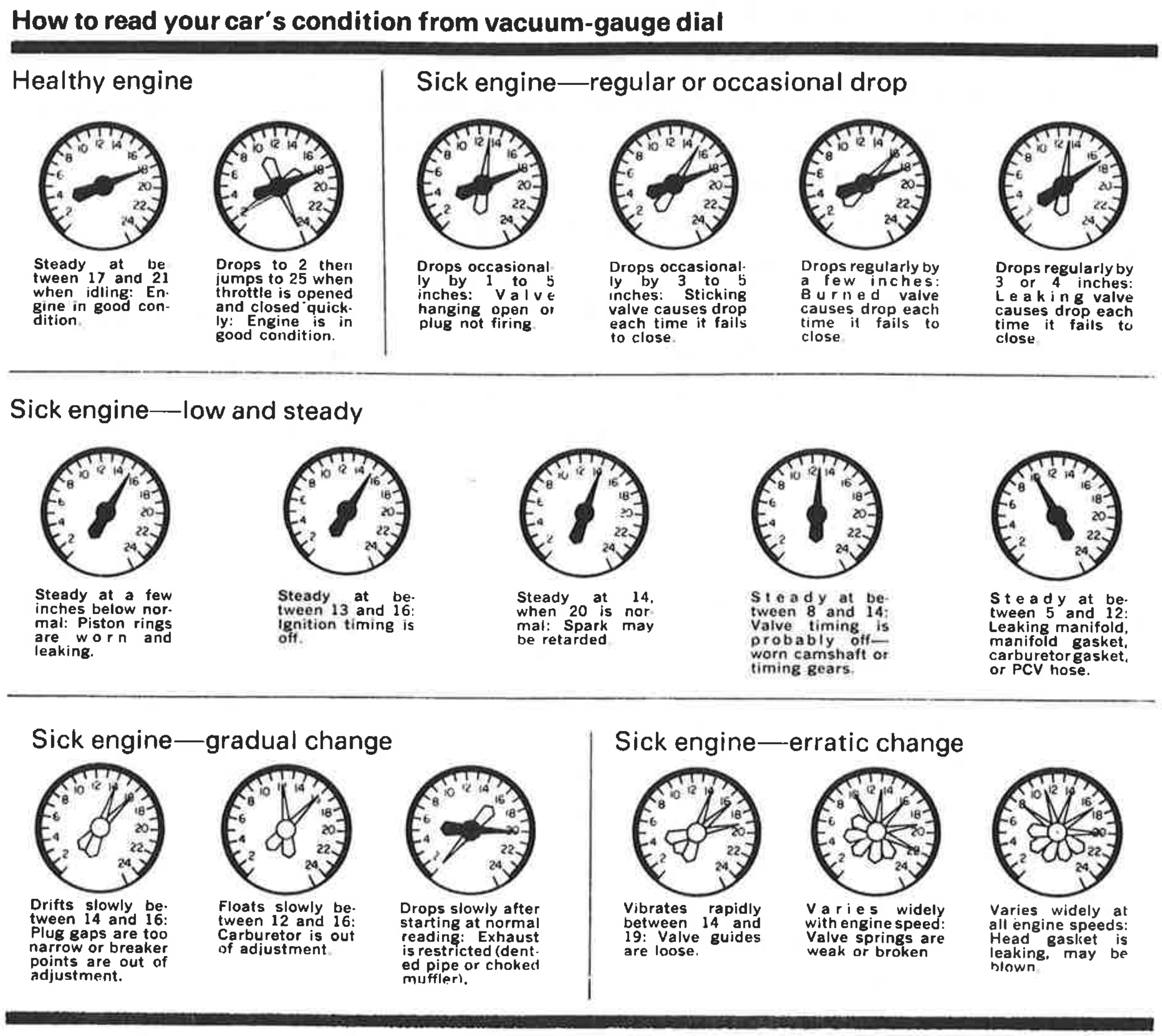


Figure 4-1. Vacuum Gage Diagnostic Applications (Ref. 4-1)

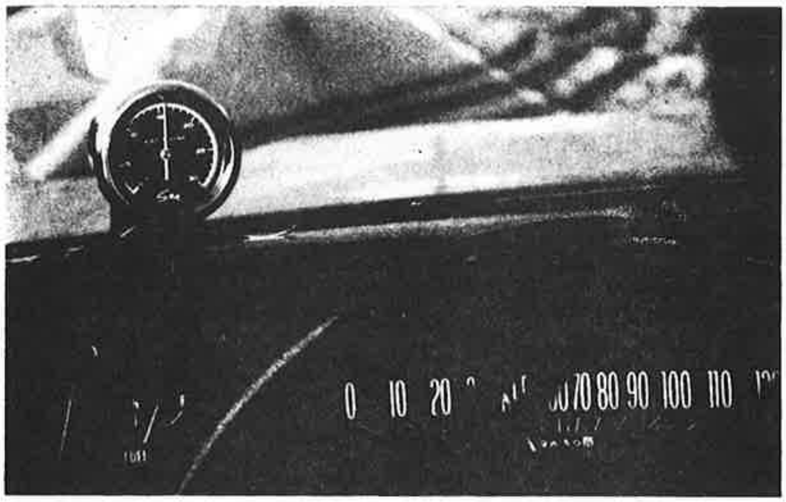
Figure 4-2 illustrates a typical vacuum gage kit and its relative position when mounted atop the dash. Gages can also be mounted under the dash or on the steering column. As shown in Figure 4-3, face designs may vary from a simple range reading to colored zones for easy reading.

An alternative means of providing vacuum-based engine load information to the driver is by means of lights rather than a dial. In this design, a vacuum gage diaphragm operates a switching device either to actuate a light when the vacuum reading drops below a certain level or to turn on different colored lights corresponding to the different economy zones. One instrument, the Expert 400 Mileage Maker, manufactured by Cornelius Engineering Center, Inc., Minneapolis, Minnesota, utilizes four different colored lights corresponding to "best," "good," "fair," and "poor" fuel economy.

Another vacuum device that utilizes a light is the Econ-O-Lite unit manufactured by Burroughs Tool and Equipment Corporation, a division of Owatonna Tool Corporation, Owatonna, Minnesota. The light flashes when the vacuum falls below a predetermined level.

Still another means of providing vacuum-based engine load information for the driver is by means of a two-color piston such as the Accelerite Linear Vacuum Gage manufactured by C&E Enterprises, Inc., Jacksonville, Florida, as shown in Figure 4-4. The Accelerite uses a vacuum-operated, spring-loaded, fabric-reinforced diaphragm to move the piston. The Accelerite unit is calibrated to start movement and to exhibit color change from the yellow economy range to the blue power range at 10.5 in. Hg of manifold vacuum and to complete its change in color signal at about 5.5 in. Hg. The Model AC-1 Accelerite incorporates an audible warning characteristic. The sound is emitted when the instrument detects the onset of over-acceleration. The sound persists until pressure on the accelerator is lessened.

All of the big four American automobile manufacturers offer vacuum-actuated devices for drivers to monitor fuel consumption.



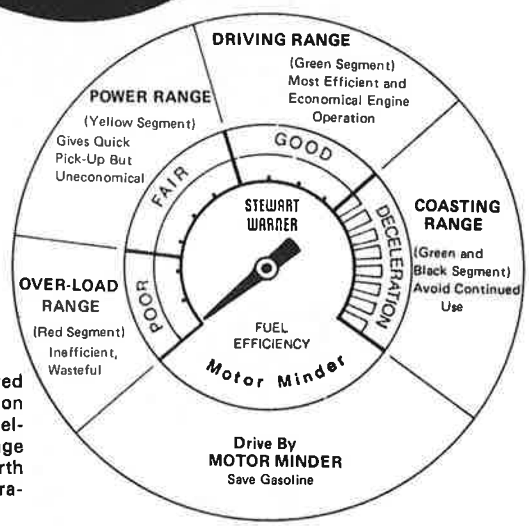
Mounting gauge atop dash, in line of sight, makes fuel-minding more effective, but takes extra hardware. Most gauges have in- or under-dash mounts.

Typical kit includes gauge, instruction sheet, dial light, Tee and manifold adapters, 6-in. and 60-in. hoses.

Gauge fits inside mounting cup (above) for top-of-dash or steering-column use. Extra hardware adds about $6.

Figure 4-2. Typical Vacuum Gage Kit and Mounting (Ref. 4-2)

Standard vacuum gauge is shown at left. This one's made by Teleflex, Inc., Limerick, Pa., and is available at auto parts stores. Actual gauge isn't large. Most gauges, including this one, measure about 2¼ inches in diameter.



Face of Stewart-Warner gauge is divided into four colored sections for easy reading. Starting at lower left, first section is red, indicating poor fuel economy. Second section is yellow, for fair economy. Next section, marked Driving Range and colored green, indicates maximum fuel economy. Fourth section (far right) is in green and black and covers deceleration.

Figure 4-3. Vacuum Gage Face Design Variations (Ref. 4-3)

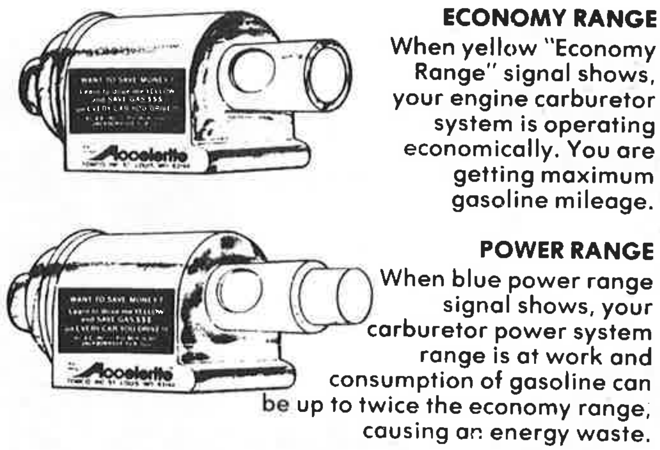


Figure 4-4. Accelerite Vacuum Device (Ref. 4-4)

General Motors, Ford, and American Motors offer as optional equipment in various models both a vacuum gage or a warning light that turns on when the intake manifold vacuum drops below a preset level. The faces of the vacuum gages are divided into colored zones. All of these units are mounted on the instrument panel. Figure 4-5 illustrates typical installations of the vacuum gages in new passenger cars.

Chrysler offers only a warning light device called the Fuel Pacer System. This device is a vacuum-switched signal that utilizes the turn indicator light mounted on the left front fender. Above about 5.5 in. Hg the light remains off. Between 5.5 and 4.5 in. Hg the light may blink rapidly in response to vacuum fluctuations. Below about 4.5 in. Hg the light remains on. The vacuum values of 4.5 and 5.5 in. Hg were chosen because at approximately 5 in. Hg the carburetor power jet is activated causing the air-fuel ratio, and thus the fuel economy, to decrease. Figure 4-6 illustrates the salient features of this system.

Vacuum gauges used on Pontiac (above), American Motors (above, right), and Ford (middle right) automobiles are inset in dashboards. Although designed for automobiles, gauges can easily be adapted for use on RV's.

Figure 4-5. Typical Vacuum Gage Installations in New Cars (Ref. 4-3)

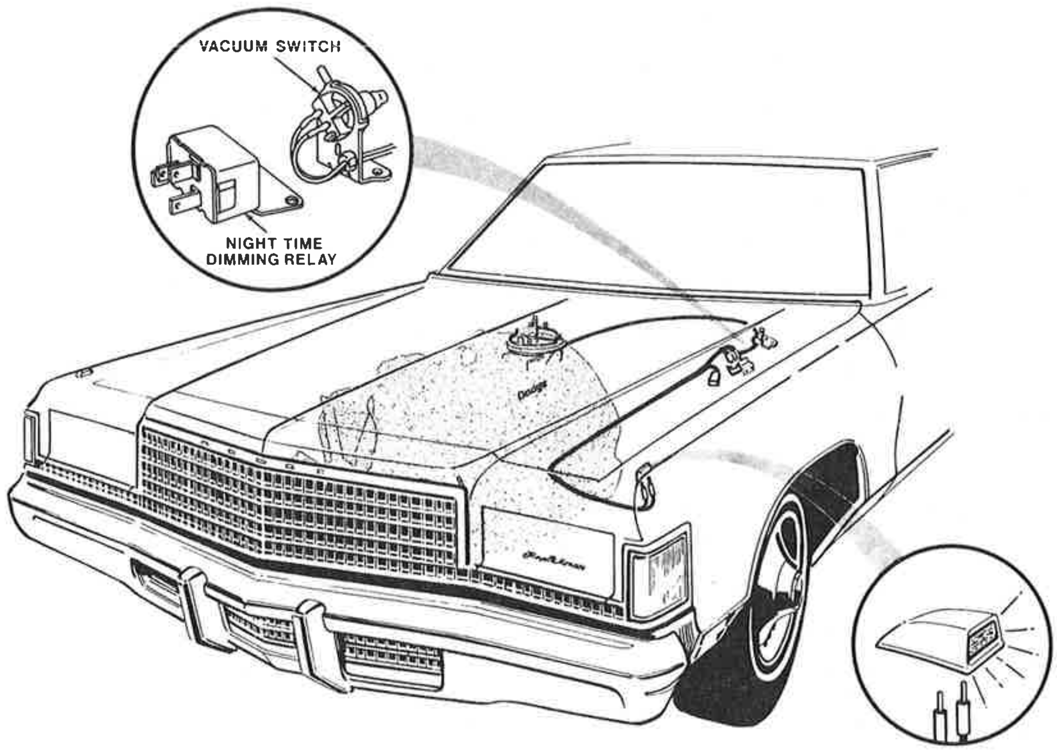


Figure 4-6. Chrysler Fuel Pacer System (Ref. 4-5)

Claims of fuel economy improvement by the manufacturers of vacuum devices range from 10 to 25 percent. Typical vacuum devices range in price from about \$5 to \$35 with at least part of the price difference being due to the type of housing and mount. In general, vacuum devices are relatively simple to install. Installation estimates range from 15 to 90 minutes, depending on the availability of the proper fittings and a convenient place to attach the vacuum line to the engine, as well as the selected position of the gage on the dash board.

4.1.3 Applicable Test Results

Vacuum devices are the only driver aids that have undergone any appreciable amount of testing to determine their merits in aiding the driver to improve fuel economy. These data are summarized in Table 4-1 and discussed below.

The U.S. Postal Service tested the Econ-O-Lite (light flashes when the vacuum falls below a preset level) (Ref. 4-6). The Econ-O-Lite was first tried on a half-ton mail delivery truck over a test course. Fuel economy improvements were only about one percent. It was then installed on 6 one-quarter-ton postal delivery trucks. Data were collected for three weeks before installation of the device and for three weeks after installation. Two of the six drivers obtained about 9 percent fuel economy improvement with the Econ-O-Lite while the other four drivers obtained decreases in fuel economy of 2 to 17 percent. In general, the drivers were negative in their opinion of the value of the device as a fuel economy aid. Some also felt there was a possible safety hazard. The drivers also felt that the device was too sensitive; that is, it turned on too frequently, even for very moderate acceleration.

The City of Jacksonville, Florida, tested the Accelerite device on five 1974 one-half-ton Dodge trucks for a period of one month (Ref. 4-7). They reported an average gas-mileage savings of 17 percent.

The National Park Service at Joshua Tree National Monument tested four Accelerite devices for six months on "high-mileage" vehicles (Ref. 4-8). They reported a 10 percent reduction in fuel consumption.

Ryder Truck Lines tested the Accelerite device on vehicles involved in stop-and-go driving (Ref. 4-9). They thoroughly explained the use and benefits of the device to the drivers but offered no rewards for improving their fuel economy. They found a fuel economy improvement of 10 percent.

The Accelerite device was also tested by the U.S. Postal Service (Ref. 4-10). It was installed in two one-half-ton trucks of different makes.

TABLE 4-1. MANIFOLD VACUUM DEVICES—TEST DATA[a, b, c]

Device	Tested By	Vehicle	Fuel Economy Results
Econ-O-Lite	Postal Service	One 1/2-ton truck Six 1/4-ton trucks	~0.1 mpg improvement ~1.0 mpg improvement for 2 of 6 trucks
Pontiac Vacuum Gage	Employees of WWJ-TV, Detroit	Pontiac	6.9% improvement
Ford Vacuum Gage		Ford	24.6% improvement
Plymouth Fuel Pacer		Plymouth	23.1% improvement
Accelerite	Ryder Truck Lines		10.2% improvement
	Postal Service	One 1/2-ton truck One 1/2-ton truck	3% improvement 7% improvement
	S. V. Shelton, Georgia Institute of Technology	5 vehicles	11.37% average improvement (between 8.5 and 13.6% with 95% confidence level)
	City of Jacksonville, Florida	Five 1/2-ton trucks	17% improvement
	National Park Service	Four vehicles	10% improvement

[a]Above tests all very limited

[b]Impossible to separate effects of device and instructions

[c]Motivation may be extremely important factor (more negative results involved fleet vehicles)

Data were recorded for five weeks before the device was installed and for 26 days after installation. The first vehicle was driven over a test course to simulate an actual mail delivery route. It achieved 11.6 miles per gallon (mpg) without the Accelerite and 11.95 mpg with the Accelerite, an increase of only 0.35 mpg. The second vehicle achieved 4.06 mpg without the Accelerite and 4.35 mpg with the Accelerite, an increase of 0.29 mpg or about 7 percent. Even though there was some fuel economy improvement, the Postal Service did not recommend the installation of more Accelerite devices. They felt that after the first few days of operation the driver would ignore the device. They also felt that it was a distraction that could possibly cause accidents.

Dr. Sam V. Shelton, Consulting Engineer and Associate Professor of Mechanical Engineering at Georgia Institute of Technology, tested the Accelerite device by installing it on five vehicles, each driven by the same driver during the test (Ref. 4-11). Total mileage travelled by the five cars was 10,861 miles. He found that the average miles per gallon improved 11.37 percent. His statistical analysis indicated that with a 95 percent confidence level the fuel economy improvement was between the bounds of 8.5 percent and 13.6 percent.

The Accelerite manufacturer also reported three other tests of the device with fuel economy improvements ranging from 1.9 percent to 12 percent.

Three employees of Station WWJ-TV, Detroit, Michigan, drove automobiles with the vacuum devices offered by General Motors, Ford, and Chrysler and reported the results on a television broadcast (Ref. 4-12). The Pontiac and Ford vehicles were equipped with vacuum gages, while the Plymouth was equipped with the Fuel Pacer. These cars were driven for a week with the gages deactivated. Then they were driven over a weekend while monitoring the devices. The Pontiac, Ford, and Plymouth obtained 14.42, 10.16, and 17.34 mpg, respectively, without the devices. With the devices activated, a 1-mpg increase was achieved in the Pontiac, a 2.5-mpg increase in the Ford, and a 4-mpg increase in the Plymouth.

The tests described in this section were very limited in scope; many factors related to driving behavior that could influence fuel economy were not considered. Generally, no discussion is provided in the reported test results of the amount of instruction given the drivers on how to utilize the device and also on how they should drive in order to improve fuel economy. It is possible that some of the improvement observed was achieved because of the instruction alone. Therefore, it is impossible to draw any firm conclusions from these test results. However, they do seem to indicate that vacuum driver aid devices and driving instruction may have some benefit in improving fuel economy.

The cases where the test results were negative involved fleet vehicles. In one of these cases, the devices appear to have been improperly adjusted. Even more important, the drivers may not have been properly motivated to increase fuel economy. Consequently, there may have been no incentive to attempt to drive according to the device. As discussed in Section 6, motivation is essential to improving fuel economy in fleet vehicle operations.

4.2 ENGINE AND VEHICLE SPEED DEVICES

4.2.1 Operating Principles

There are two speed parameters available for use in driver aid devices: engine speed and vehicle speed. Vehicle speed (miles per hour) is sensed by attaching equipment to the existing speedometer system. Engine speed (revolutions per minute) is normally sensed, as with a tachometer, by connecting electronic circuitry to the distributor. Another technique used in the past for sensing engine speed is to modify the distributor and mechanically attach a cable, similar to a speedometer cable, to the distributor shaft. This method is rarely used now. Either of these speed parameters can be used as input to a driver aid device, either by itself or, as is the case with miles-per-gallon meters, in conjunction with other vehicle parameter inputs. This section will address those devices that depend only on speed for their operation.

The use of vehicle speed in driver aid devices is motivated by the fact that, under steady-state cruise condition, fuel economy is related to driving speed, as shown in Figures A-6 and 3-1. Most cars achieve maximum economy somewhere between 30 and 45 miles per hour. Economy decreases at lower speeds because of engine inefficiency, and at higher speeds because of the rapidly increasing power required to overcome wind resistance. It is not considered feasible to alert the driver overtly as to uneconomical operation at low speeds because much normal urban and suburban driving is done at low speeds, in stop-and-go traffic and in other driving situations over which the driver has limited control. However, vehicle speed is a useful driver aid parameter at highway speeds where the driver has more control over his driving. The typical vehicle speed devices warn the driver whenever a preset or driver-selected speed is exceeded.

The advantage of using vehicle speed as a parameter is that it is easily and accurately sensed, it is readily understandable by the average driver, and speeding carries with it the potential penalty (a negative motivation) of being stopped by the police. The disadvantages of using vehicle speed in a driver aid device, however, are as follows:

a. It is not frequently useful at the lower speeds where economy losses are the highest. Thus, the potential for saving fuel is reduced.

b. Most of the vehicle miles traveled nationally (about 75 percent in 1970, even before the inception of the lower 55 miles-per-hour national speed limit) are at speeds that average less than 55 miles per hour.

c. While speed is a parameter easily understood by the average driver, the relationship between speed and fuel economy is not.

d. Even speeds that are economical under normal conditions can be uneconomical if driven in a lower gear or up a long grade.

e. Vehicle speed by itself does not usually reflect the erratic driving habits that are generally felt to be the chief cause of poor fuel economy.

The driver aid devices that use engine speed as the sensed parameter perform in essentially the same manner as vehicle speed devices when the vehicle is in high gear, and thus have many of the same advantages and disadvantages as the vehicle speed devices. However, engine speed is preferred in most applications because higher-than-necessary engine speeds, for any given vehicle speed, result in excessive fuel consumption.

This situation can occur either with automatic or manual transmissions, when aggressive driving habits are practiced. High acceleration rates cause the shift points of automatic transmissions to be delayed until higher engine speeds are reached. Manual transmissions are frequently held too long in a lower gear by the driver during acceleration or cruise, which also results in increased fuel consumption. Therefore, a warning signal, triggered at a given engine speed, while not as well understood by the average driver as vehicle speed, could serve to moderate both maximum vehicle speed and the harshness of driver operation.

The attachment of vehicle speed devices is generally accomplished by inserting a transducer somewhere along the speedometer cable. This insertion can be done most easily either between the transmission and the cable, or between the cable and the speedometer. In some instances, the introduction of the transducer results in sharp bends in the cable and produces noises or erratic speedometer behavior. These problems necessitate cutting the speedometer cable and installing the transducer in a straight portion of its run. The transducers generally take the form of a small generator, whose voltage or frequency is proportional to speed, or a switching mechanism whose contacts make and break at a rate proportional to speed. The transducer output is then connected by wires to the device's logic circuitry. Several older luxury cars incorporated a warning flag and switching mechanism directly within the speedometer mechanism itself.

Current engine speed driver aid devices (and tachometers as well) are invariably attached to the distributor and coil lead with a single wire. The logic circuitry of the device then senses the rate of transients introduced each time a spark plug fires, that rate being directly proportional to engine speed. The means for sensing engine speed is simple and the required installation time for the sensors is minimal.

4.2.2 Specific Engine and Vehicle Speed Devices

A wide variety of speed warning devices is available on the market or as preproduction prototype systems. These devices cost between

$10 and $20 and use simple circuitry that allows some speed setting adjustment on installation.

Safety Systems, Inc., St. Paul, Minnesota, markets an MPG Mileage Monitor that connects to the distributor to sense engine speed. After installation, the car is driven at the desired speed limit and the unit adjusted until a red light on the panel-mounted control box comes on. Thereafter, the light will switch on whenever that speed is exceeded. Installation time is 30 minutes, and the list price is $14.95.

The Perfect Circle Division of Dana Corporation, Toledo, Ohio, has made numerous prototypes of an Excessive Speed Signal that connects to the distributor to sense engine speed. After installation, a trip point adjustment must be made. A subsequent engine speed sustained at least several seconds and sufficiently high to exceed the trip point generates an audible alarm. The unit can be mounted out of sight of the driver. Installation time is 15 minutes, and the anticipated price is $12 to $15.

Carter's Safety Systems, Inc., Charleston, West Virginia, markets a Monitrex speed control that attaches to the distributor to sense engine speed. This unit has a dial calibrated in miles per hour for use in setting the alarm speed. When the desired speed is reached, an audible buzzer is sounded and a normally green panel light changes to amber. When the alarm speed is exceeded, the amber light turns to red, a siren is sounded, and a digital counter increments to record the violation. The controller also has two theft positions on the control panel, which either prevent engine operation completely or disable the engine if a speed of 20 miles per hour is exceeded. Installation time is 30 minutes, and the list price is $59 (in quantity).

Rex Chemicals, Inc., Wilson, North Carolina, has prototypes of a Flasher speed control that connects to the distributor to sense engine speed. This device connects to the four-way turn signal system of the car, and starts the turn signals flashing whenever the selected speed is exceeded. The interior turn signal indicators warn the driver and the exterior flashing turn lights identify the speeder to police, which is said to motivate the driver to observe the speed limit. Installation time is 30 minutes, and the estimated price is $20.

The J. C. Whitney Co., Chicago, Illinois, markets an Electronic Speed Warning device that attaches to the distributor to sense engine speed. The controller attaches to the top of the dash and a red light is illuminated when the adjustable speed limit setting is exceeded. Installation time is 30 minutes, and the list price is $6.49.

The Stewart-Warner Corporation, Chicago, Illinois, has prototypes of a High-Speed Warning Alarm that is similar in nature to the Perfect Circle device. Installation time is 30 minutes, and the anticipated price is from $7 to $50, depending on production quantity.

The DBA Co., France, markets an Avimax speed controller (Figure 4-7) that senses vibration in the speedometer cable. The desired speed limit is selected by depressing one of six buttons, labeled 60, 80, 90, 100, 120, and 140 kilometers per hour. A siren is sounded whenever that speed is exceeded. An "off" button position is also included. Installation time is 30 minutes, and the list price is unknown.

Figure 4-7. Avimax Speed Controller (Ref. 4-13)

The speed control devices all purport to save gas, but specific claims are not always made, and supporting test data are not included. Safety Systems suggest that the unit be set for 35 to 40 miles per hour for best economy, and then set lower "as your driving habits improve" for "even further fuel economy." Perfect Circle makes no claims. Carter's Safety System implies a 36 percent reduction in gas consumption at highway speeds. Rex Chemicals suggests a 21 to 28 percent fuel savings at highway speeds. J. C. Whitney, Stewart-Warner, and the DBA Company apparently do not make mileage claims.

4.3 FUEL FLOW DEVICES

4.3.1 Operating Principles

There are two types of fuel flow devices that can provide information to a driver on the amount of fuel he is using and possibly on how to drive more economically: the fuel flow rate meter and the fuel totalizer meter. Both are inserted in the fuel line of the car, generally between the fuel pump and the carburetor. The flowmeter measures the instantaneous rate of fuel flow into the carburetor. The fuel totalizer meter measures the total amount of fuel used over a given period of time. There are a great number of flowmeters available on the market. Obviously only those that lend themselves to an easily readable display on the dashboard of the car are suitable as a driver aid device.

Since the flowmeter indicates how much fuel is being used at a given time, it does give a driver some information to help him drive more economically. For example, the flowmeter will indicate that the automobile fuel flow rate will be greater during a fast acceleration than during a moderate acceleration. It would also show the difference in fuel used when driving in second gear compared to driving in high gear at a given speed. A disadvantage of the flowmeter is that, while the fuel flow rate increases with vehicle speed, the fuel economy also increases with speed up to about 35 to 45 miles per hour. At higher speeds, the flowmeter is a more direct indicator of fuel economy effects. As will be discussed later, the principal use of a fuel flow rate meter as a driver aid device is when it is used as part of a miles-per-gallon meter.

The fuel totalizer meter will indicate the amount of fuel used from any selected initial time. It is designed so that it can be reset to zero at any time. Without a fuel totalizer gage a driver can determine how much fuel he has used only when he fills his tank at the service station. Since it may take days or even weeks in some cases to use a tank of gasoline, and since many different types of driving may be involved such as business, pleasure, and shopping, it is difficult for the driver to utilize this information to improve his driving habits. On the other hand, the fuel totalizer meter indicates how much fuel is used for any length of trip.

The totalizer meter can be used in a number of different ways. For example, a driver may wish to minimize the amount of fuel he uses in driving to work by varying his rate of acceleration and cruising speed. The meter would indicate if lowering his rate of acceleration reduces his fuel consumption or which cruising speed minimizes the amount of fuel used. The driver could also use the device to select a route to work that minimizes his fuel consumption. Another advantage of a fuel totalizer is that it provides a direct indication of how much fuel is used in unnecessary trips. For example, if a housewife found that one of her frequent trips for groceries consumed about 1.5 gallons or about one dollar's worth of gasoline, she might be inclined to reduce the number of her shopping trips. The principal advantage of a fuel totalizer meter is that it gives the driver a direct measurement of the quantity that he is trying to minimize, namely, the amount of fuel used. A disadvantage is that it does not give him an instantaneous indication of how he should drive more economically. In the absence of information from other types of driver aid devices, he must determine this by varying his driving habits by trial and error over a number of trips.

4.3.2 Specific Fuel Flow Devices

There are a great many devices available on the market to measure both the flow rate and the total flow of liquids. However, to be useful for automobiles, a flowmeter must (1) be able to measure the low flow rates typical of automobiles (1 to 20 gallons per hour), (2) have a convenient electrical or mechanical readout, (3) be relatively small in size, and (4) be relatively inexpensive. Flowmeters typical of those available for automobiles are manufactured by SpaceKom, Inc., Santa Barbara, California, and FloScan Instrument Company, Seattle, Washington. These companies manufacture instruments especially for the automobile market and are currently in production with both flowmeters and fuel totalizer meters.

The SpaceKom flow transducer is a variable orifice-type flowmeter in which a ball is pushed against a spring by the gasoline flow (see Figure 4-8). The ball interrupts the path of light from a lamp falling on a photoresistor. As the ball moves, more light is allowed to fall on the photoresistor. A filter is used in front of the photoresistor so that the resistance increase is linearly proportional to the rate of fuel flow. The instrument is mounted in the fuel line between the pump and the carburetor. It is claimed to be accurate to within ±2 percent. The flow range is from 0 to 20 gallons per hour. SpaceKom also manufacturers a fuel totalizer meter that basically integrates the output of their flowmeter. The totalizer is also claimed to be accurate to within ±2 percent and reads up to 100 gallons in 0.01-gallon increments.

The FloScan flow transducer utilizes a rotating turbine wheel. The gasoline enters the flowmeter radially and exits axially. The three blades in the rotor interrupt a light path between a light bulb and phototransistor as they rotate. The flow rate is directly proportional to the frequency of the instrument's pulsing electrical signal. The flowmeter has a range up to 20 gallons per hour and is claimed to be accurate to ±1.5 percent. FloScan also manufactures a totalizer meter that is connected to their flow transducer. Similar to the SpaceKom device, it can also measure up to 100 gallons in 0.01-gallon increments.

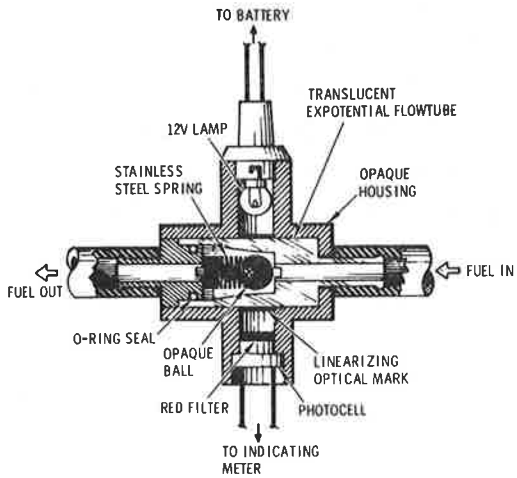


Figure 4-8. Cross Section of SpaceKom Flowmeter (Ref. 4-14)

Because the operating environment for an automobile fuel flowmeter can be severe under certain conditions, there are a number of possible error sources (Ref. 4-15). The gasoline can change in both density and viscosity because of temperature changes. At higher temperatures bubbles can form that can cause the flowmeter to give inaccurate readings. The combination of bubbles and the pulsating fuel pump pressure can cause fuel to flow backwards through the meter, which in some meters can cause the fuel to be counted twice. The needle valve in the float bowl of a carburetor can also cause unsteady flows. For meters utilizing a light beam, the opacity variations of the gasoline because of its color variations could also cause errors. Fluctuations in the voltage supply to the meter as well as electronic interference caused by the ignition system are also possible error sources. Some types of meters may be affected by the attitude of the meter. Finally, the vibration of the instrument can cause errors. It should be noted that the accuracy levels claimed for some of these automotive fuel flow devices are disputed by results obtained in test evaluations by a number of automobile manufacturers.

FloScan claims to have minimized the vapor bubble and pulsation error sources by the design of their flow transducer and by the use of a pulsation damper. FloScan states that, for maximum accuracy, in-car calibration is desirable for all flow transducers.

The National Bureau of Standards has a contract from the Department of Transportation, Transportation Systems Center, to determine the accuracy of fuel flowmeters suitable for use in an automobile. Dr. Baldwin Robertson is the principal investigator. The meters that he tested are listed in Table 4-2. Only the first five have a low enough price to make them practical for a large-scale test program.

TABLE 4-2. FLOWMETERS TO BE TESTED BY NATIONAL BUREAU OF STANDARDS (Ref. 4-16)

Flowmeter Type	Cost, dollars
Variable Orifice (ball and spring)	39
Ball in Torroidal Passage	55
Turbine	150
Vortex (rotating toothed disc)	120
Automatically Filled and Dumped Container	295
Positive Displacement	2370
Pistons on Crankshaft	3975
Positive Displacement	8600

The SpaceKom gallons-per-hour meter lists for $49.50. The SpaceKom totalizer meter lists for $56.50 (complete). Prices for the standard FloScan flow transducer are not normally quoted separately since it is sold as part of the miles-per-gallon meter. The latest FloScan flow transducer (Model No. 255-PB-15), which is designed to minimize errors due to the automobile environment, lists for $150. The totalizer unit costs an additional $119.

4.4 ACCELERATION DEVICES

4.4.1 Operating Principles

Available acceleration driver aid devices determine acceleration by velocity difference as sensed by pickup from the speedometer cable or cable drive.

On a level road, the acceleration of an automobile is a direct measure of the horsepower being expended over and above the power required to maintain constant cruise speed. Therefore, the acceleration is also an indicator of acceleration-induced fuel consumption. Generally speaking, the higher the rate of acceleration, the higher the fuel consumption.

An important advantage of an accelerometer over other types of driver aid devices is that it is the only device that can measure deceleration rates. Large decelerations of an automobile occur when the driver takes his foot off the throttle suddenly at high speeds or in low gear and when he brakes severely. Excessive and frequent deceleration is an indication of poor driving associated with unnecessarily high accelerations and speeds. A driver can reduce the number of large decelerations by not accelerating to a speed that is too high for traffic conditions and by anticipating traffic conditions ahead to avoid sudden stops. A device that alerts the driver when he decelerates above some predetermined value which is determined as being the upper limit for good economical driving may be a useful driver aid device.

Acceleration has several disadvantages as a driver aid fuel consumption indicator. First, it is not a measure of steady-speed fuel economy because, by definition, the acceleration is zero at a steady speed.

Therefore, an accelerometer would not indicate to the driver the difference in fuel economy between cruise at, e.g., 45 and 65 miles per hour, although this difference could be considerable. Secondly, upgrades and downgrades can drastically affect the vehicle's horsepower requirements and, thus, fuel consumption. The accelerometer provides no information as to desirable speeds for negotiating these grades.

4.4.2 Specific Acceleration Devices

There are a number of accelerometers on the market that would be suitable for automotive use. One unit that is designed specifically for automobiles is the Dynamic Dynamometer manufactured by Autotronic Controls Corporation, El Paso, Texas. It utilizes a speed transducer connected to the speedometer cable. By means of suitable circuitry it measures the rate of change of the automobile speed (i.e., the acceleration) and displays it on a dial. The instrument is calibrated in g's. Autotronic Controls also manufacturers a variation of the device known as the Model 702 Pacesetter or the Electronic Power Indicator. Instead of a dial this device uses an indicator panel with colored lights. For very low values of acceleration the green light is illuminated. For higher values of acceleration the yellow light is illuminated, and for high values the red light illuminates. Both the red and green light illuminates for deceleration. The Pacesetter unit is not yet in production, however.

The price of the Dynamic Dynamometer is $139. A similar accelerometer is manufactured by SpaceKom, Inc., Santa Barbara, California. Its accuracy is claimed to be 3 percent and it is priced at $39.50. Installation time for either of the acceleration devices should be about one-half to one hour.

4.5 MILES-PER-GALLON (MPG) METERS

4.5.1 Operating Principles

A miles-per-gallon (MPG) meter is an instrument that gives the driver an instantaneous indication of the miles per gallon being obtained by his car. This reading is accomplished by simultaneously measuring the speed of the car with a speed sensor and the engine fuel consumption with a flow rate meter. The miles per gallon are then simply obtained from the ratio of the speed of the car (miles per hour) and the fuel flow rate (gallons per hour) to give miles per gallon. For the case of an electrical analog type of instrument, if the speed sensor produces a voltage that is linearly proportional to the speed of the car and the flowmeter varies a resistance linearly proportional to the fuel flow rate, then the current in the circuit, which can be measured simply by an ammeter, will be proportional to the miles per gallon. Figure 4-9 indicates the components and installation features of such an MPG meter.

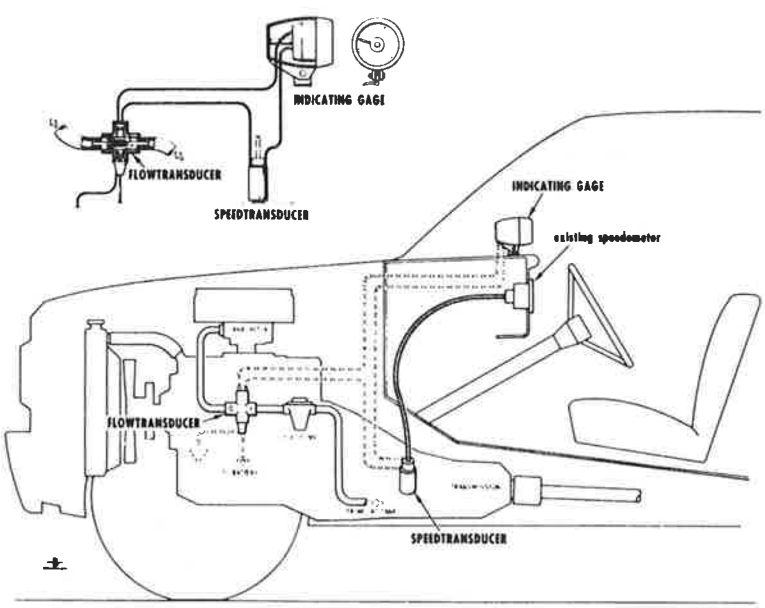


Figure 4-9. Components of SpaceKom Miles-Per-Gallon Meter (Ref. 4-17)

For a car not equipped with a MPG meter, the miles per gallon can be determined simply by noting the number of gallons required to fill the tank of the car and the number of miles traveled since the last tank fill-up. This method, while reasonably accurate if averaged over a number of fill-ups, provides only an average value of fuel economy for a number of trips that may include many different types of driving. It does not provide a direct indication to the driver of how to drive more economically.

Since the MPG meter gives an instantaneous reading of fuel economy, the driver can determine how his particular driving habits affect fuel economy. For example, it will indicate to the driver that the miles-per-gallon reading generally decreases as the rate of acceleration increases. It will also indicate to him that his fuel economy is low at very low speeds and also at very high speeds and at which speed he achieves maximum fuel economy. Another benefit is that it will indicate to the driver how his fuel economy increases as the vehicle warms up. This information may lead him to reduce the number of short trips he makes.

The main advantage of the MPG meter, therefore, is that it gives the driver a direct instantaneous indication of fuel economy in terms that he readily understands. A disadvantage of the MPG meter is that, since it is an instantaneous measurement, it is difficult for the driver to integrate the measurements to determine how much fuel he has saved by varying his driving habits for a given trip.

4.5.2 Specific Miles-Per-Gallon (MPG) Meters

The miles per gallon are obtained by finding the ratio of the speed of the car (miles per hour) to the flow rate (gallons per hour). A speed transducer is connected to the speedometer cable to convert speed to an electrical signal. MPG meters are manufactured by two companies: SpaceKom, Inc., Santa Barbara, California, and FloScan Instrument Company, Seattle, Washington. Both companies use the flow transducers described in the previous section.

SpaceKom utilizes a speed transducer that produces a voltage linearly proportional to the speed of the automobile. Since the flow transducer produces a resistance that is linearly proportional to the flow rate, then, by applying the voltage to the resistance, the current in the circuit is equal to the miles per gallon (by Ohms law, $I = V/R$). SpaceKom produces MPG meters with ranges of from 0 to 20 and from 0 to 40 miles per gallon. They claim an accuracy of ±3 percent. The SpaceKom meter is shown in Figure 4-10.

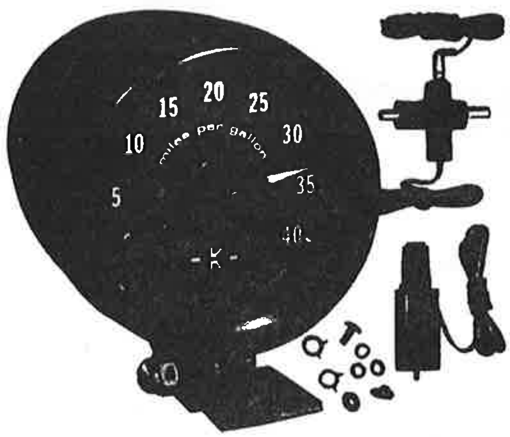


Figure 4-10. SpaceKom Miles-Per-Gallon Meter Showing Indicator, Flow Transducer, and Speed Transducer (Ref. 4-18)

The FloScan speed transducer is a rotary cam switch that grounds out six times per revolution. The number of pulses is then directly proportional to the speed of the car. The flow transducer and speed transducer pulse signals are combined electronically to produce miles per gallon.

No accuracy claims are made for the overall meter, but the flow transducer is claimed to have an accuracy of ± 1.5 percent. The FloScan meter is shown in Figure 4-11.

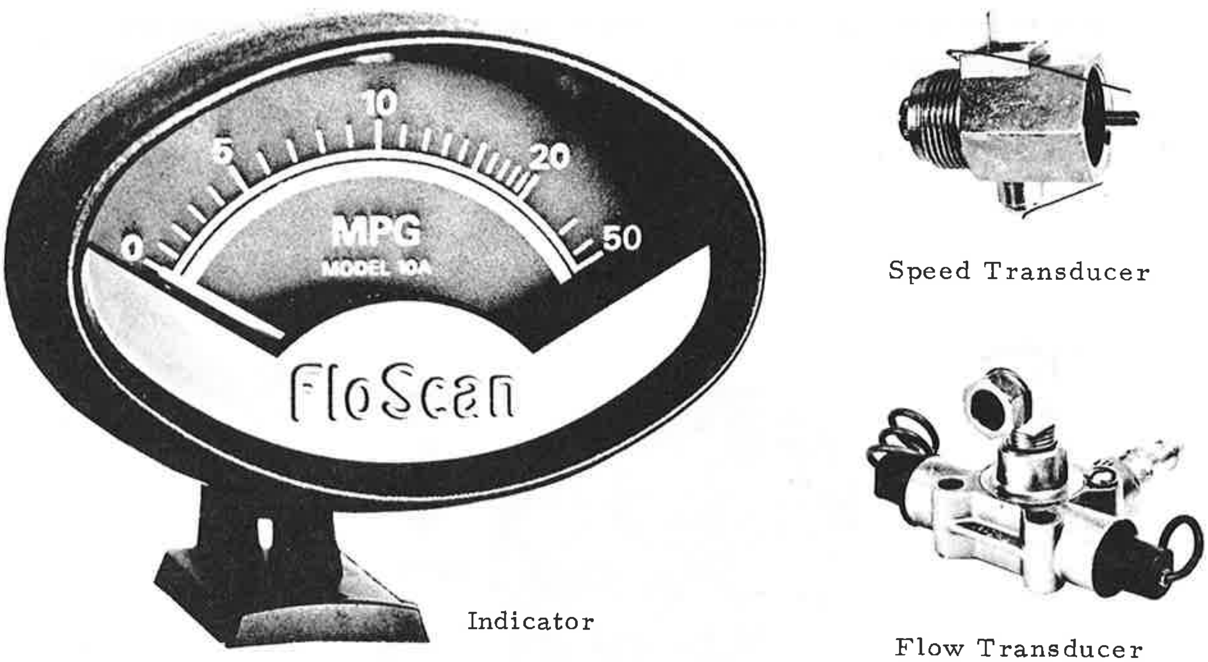


Figure 4-11. FloScan Miles-Per-Gallon Meter (Ref. 4-19)

Several U.S. automobile manufacturers have checked the accuracy of the available MPG meters and, in general, have not found them to be as accurate as claimed. For one instrument, errors as large as -30 percent and +10 percent over the scale range were reported. In addition, readings were reported to be highly nonrepeatable. It should be noted, however, that a MPG meter does not have to have a high absolute accuracy to be useful since the main benefit of the meter is to show the changes in fuel economy with various operating conditions.

Both the SpaceKom and FloScan MPG meters are in quantity production. SpaceKom has sold more MPG meters. This unit is currently listed in the Sears, Roebuck and Company catalog. The MPG meters for both companies are available for most American-made cars. The SpaceKom meter is listed at $38.99 in the Sears catalog. The standard FloScan meter lists at $110 but has been sold recently for $55.00. However, the most accurate FloScan flow transducer lists for $150.

There is more work involved in installing a MPG meter than most driver aid devices since three separate units must be installed. The flow transducer must be inserted in the fuel lines, the speed transducer connected to the speedometer cable, and the indicator mounted on the dashboard and connected to the transducer. Time estimates for installation range from as little as one-half hour to as much as 3 hours.

Test data on the fuel economy benefits of MPG meters have not been found.

4.6 AIR FLOW RATE AND AIR-FUEL RATIO DEVICES

4.6.1 Operating Principles

Air flow rate and air-fuel ratio are two parameters commonly used in engine and vehicle testing, but neither has been offered in driver aid applications. Air flow rate devices designed primarily for laboratory work are available, but no devices have been found that combine the output of air and fuel flow sensors to show air-fuel ratio directly. Therefore, neither of these parameters is currently viable as a driver aid, but a brief discussion is included here for completeness.

The air flow rate characteristics of a typical engine were illustrated in Figure 3-2. Air flow is a useful parameter in that it directly reflects both power output and engine speed, which are the two most important characteristics of vehicle operation related to fuel consumption. A continuous readout of air flow might have some value as a driver aid, but its interpretation would require a significant level of training. It would probably be more desirable to mechanize a light or buzzer readout triggered at abnormally high flow rates.

Air flow rate devices are installed in the engine's air intake system upstream of the carburetor. The rate can be sensed by measuring the pressure drop through an orifice or venturi, or by monitoring the velocity of a rotating vane driven by the air stream. Since the ratio of air to fuel is essentially constant over a wide range of engine operating conditions after warmup, it is conceivable that air flow could also prove to be a useful measure of fuel flow. The motivation for this would be the difficulties currently being experienced in developing inexpensive and reliable fuel flow devices.

The air-fuel ratio characteristics of a typical engine are presented in simplified form in Figure 4-12. The ratio is essentially constant at about 16:1 over a broad range of manifold vacuum (and power) levels. Some enrichment occurs in and near the high-vacuum idle condition when the idle jets are in operation, and again at low-vacuum, high-power conditions when fuel enrichment to about 13:1 is deliberately introduced by the carburetor's power-jet system. Because of this two-level nature of the air-fuel ratio parameter, its usefulness in a driver aid device is essentially limited to triggering a light or buzzer when fuel-rich mixtures are entering the engine. Since this same information is very adequately and inexpensively produced by simple vacuum devices, without the need for fuel and air flow sensors and the associated electronic divider network, no justification is seen for any further consideration of air-fuel ratio devices of this type for driver aids.

4.6.2 Specific Air Flow Rate and Air-Fuel Ratio Devices

Very little information on air flow rate devices exists, and no marketed version of an air-fuel ratio device as a drive aid was found.

Autotronics Controls Corporation, El Paso, Texas, markets a series of turbine-type air flow transducers with thermistor temperature

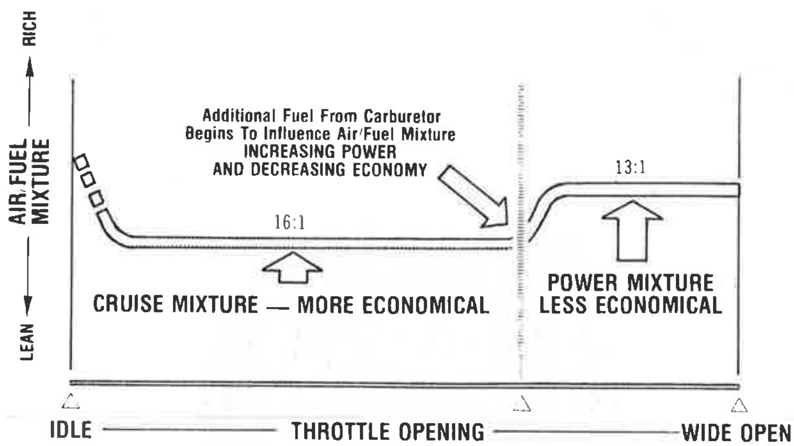


Figure 4-12. Typical Air-Fuel Ratio Variations (Ref. 4-20)

compensation and digital readout. They are currently made in very small quantities for research applications. Installation time is at least several hours. The list price is currently $592 for the Model 450F (flow rates less than 450 cubic feet per minute, which is sufficient for auto applications) but about $50 or less in quantity. The Autotronic air flow rate device has never been used in a driver aid application, and no mileage claims are made.

4.7 EXHAUST TEMPERATURE DEVICES

4.7.1 Operating Principles

Whenever fuel savings and driver education programs are discussed with commercial fleet vehicle operators, the subject arises of using sensors to read out the temperature of exhaust gases in the exhaust manifold. These devices, known as pyrometers or simply pyros (see Figure 4-13), have most commonly been used in diesel engine applications. Very little use of pyros has been made in the past with gasoline engines, but that is now beginning to change because of the severity of economic conditions and resultant operator concern.

Figure 4-13. Exhaust Temperature Gage (Ref. 4-21)

The advantage of using pyros, particularly with professional drivers trained in their interpretation, is that exhaust gas temperature is sensitive to nearly every factor that affects vehicle operation. These factors include engine and vehicle speed, road grade, ambient temperature and humidity, air-fuel ratio, misfiring spark plugs, bad ignition wiring, and even the differences between operating on asphalt and concrete roads.

The use of pyros in automobile applications is not too well developed, and the little information that does exist is often contradictory. A simplified presentation of the effects of some vehicle conditions on temperature as measured on the exhaust manifold flange of a passenger automobile is given in Figure 4-14. The solid lines indicate the influence on temperature of power variations at constant engine speed. The displacement of these lines, one from the other, illustrates the effect on temperature that occurs with changes in engine speed. Note also that a temperature limit at the higher engine speeds and power levels is approached, where even major changes in engine operation cause very little temperature change.

The dashed line in Figure 4-14 indicates the temperature characteristic for steady-state cruise speeds over a level course. These data indicate that, at any vehicle speed, temperature would rise and fall with increasing and decreasing power requirements, such as is caused by changes in grade. However, sufficient information on the behavior of these systems in automobile applications is not available to draw firm conditions as to their value as driver aid devices.

The pyro readout primarily reflects three factors: power output, late fuel burning in the exhaust manifold, and rate of gas flow. Increasing power levels raise the peak temperatures within the cylinder and hence, at the pyrometer's thermocouple. Late fuel burning, commonly caused by leaner air-fuel ratios, also increases the gas temperature in the exhaust manifold where the thermocouple is located. Increased gas flow rate, which is a function of engine speed, raises the temperature by virtue of the fact that less time is available for heat transfer (and thus lower gas temperatures) before the gas reaches the thermocouple.

For diesel fleet vehicle pyro applications, a band of acceptable temperatures, typically from 700 to 1200°F, is established. The driver is instructed to remain within these limits. The minimum temperature limit warns of inefficient, fuel-wasting, low-speed operation. The maximum

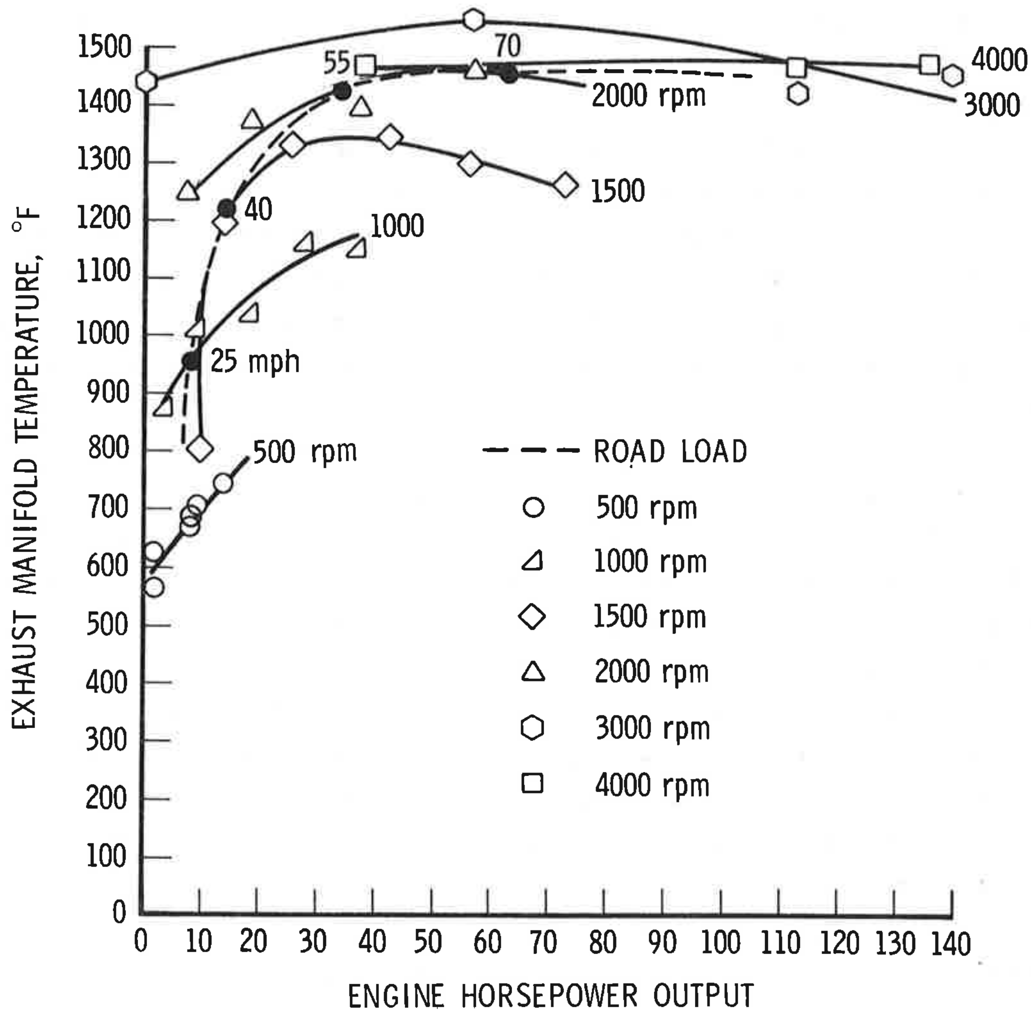


Figure 4-14. Effect of Vehicle Operating Conditions on Exhaust Temperature (Ref. 4-22)

limit identifies excessive engine loads or the danger of preignition, which has a direct relationship on the useful lifetime of the engine and which also affects fuel economy. The fact that there is a maximum possible temperature associated with the engine is not usually important, since the upper limit permitted in operation is set well below that.

4.7.2 Specific Exhaust Temperature Devices

Several commercial lines of exhaust manifold temperature devices exist. They are primarily sold for application to diesel and large gasoline engines but each can be installed in any gasoline engine. Information on two product lines is given below.

Hewitt Industries of Los Angeles, El Segundo, California, markets a fairly complete line of pyros (Figure 4-15), which includes single pyros, twin pyros (for separately monitoring the left and right banks of V-type engines), and audible or visual alarms. The gage readouts are connected to thermocouples mounted in stainless probes inserted into the exhaust manifold slightly downstream of the engine's exhaust ports. The pyrometer output can also input to an alarm system that triggers if the preset maximum operating temperature is exceeded for several seconds. This alarm drives dash-mounted warning lights or audible buzzers, accessory pens on tachographs, and even engine fuel-limiting devices to prevent engine overload. Gages are calibrated from 0 to 1500°F or 2000°F, or from 0 to 1000°C. Installation time is 2 to 4 hours. The list prices are $83 (single pyro), $146 (dual pyro) and $100 (pyro alarm). The alarm system operates off an existing pyro, so that both units must be purchased if the alarm is desired.

The ISSPRO Company, Portland Oregon, markets a line of pyrometers very similar to Hewitts. List prices are $72 (single pyro), and $184 (pyro plus alarm).

Pyrometers are not marketed as a driver aid per se; thus, no numerical mileage claims or test results are made in the literature. However, very strong statements are made by fleet operators relative to the fuel saving advantages of using pyrometers.

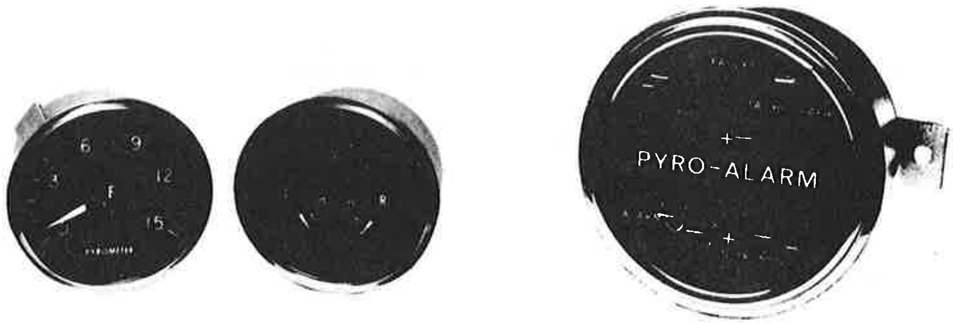


Figure 4-15. Typical Hewitt Pyrometers and Pyro-Alarms (Ref. 4-23)

4.8 SPEEDOGRAPHS AND TACHOGRAPHS

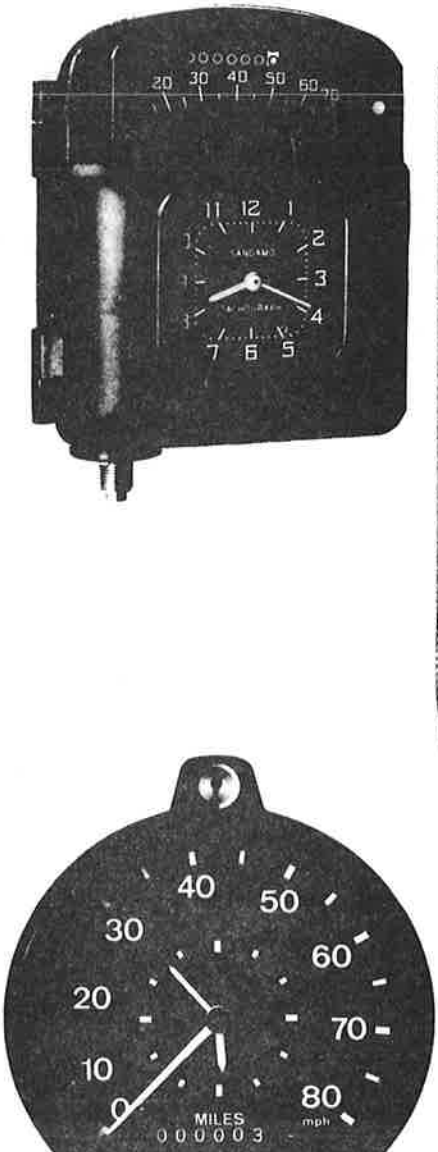
4.8.1 Operating Principles

Speedographs and tachographs are essentially small chart recorders that make a continuous and permanent record of vehicle speed (speedograph) or engine speed (tachograph). These devices are not normally considered to be driver aid devices in the usual sense, since their primary function is simply to record engine or vehicle speed and other parameters for future reference. They have been included in this report, however, because they are commonly accepted as a critical, even indispensable, device in fleet driver education and fuel savings programs. It is the opinion of most fleet vehicle driver-training experts[1] that, without the use of these devices to permit the continuous evaluation of driver performance and the subsequent discussion of deficiencies, even the best driver education program is a waste of time and money.

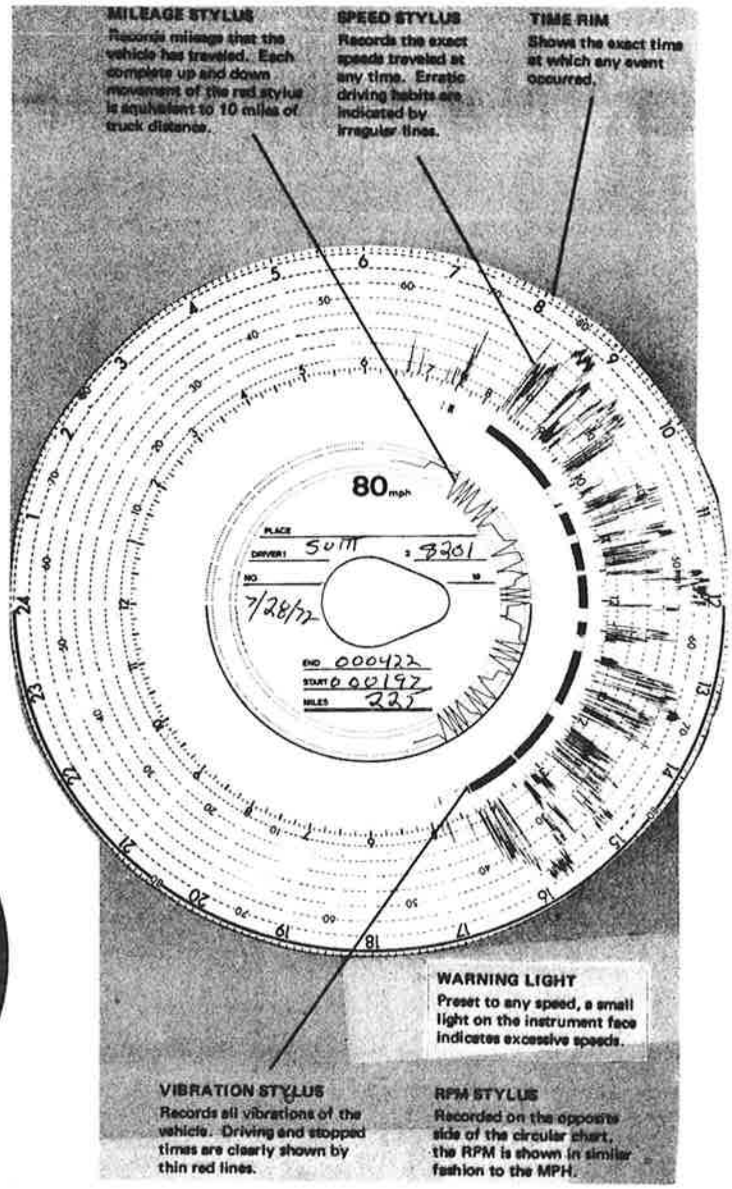
[1] One of the most outstanding programs of driver training and education can be found at the Transportation Department of the Douglas Aircraft Company in Long Beach, California.

Training and education for fleet vehicle drivers are generally accepted as the most valuable methods for improving fuel economy and lengthening engine life. The training stresses the importance of remaining within legal speed limits, and of operating the engine and transmission properly using driver aids such as tachometers, vacuum gages, and exhaust gas pyrometers. However, if some method is not provided for constantly evaluating each driver's conformance with the driving rules on a day-to-day basis, the drivers inevitably revert to their original habits. Thus, the tachographs and speedographs are necessary to supply that continuous record of driving behavior. The recording is then used to illustrate to each driver his particular deficiencies throughout the entire driving day, and demonstrate constructively where improvement is needed.

Two typical configurations and a sample chart record are shown in Figure 4-16. The exterior designs vary from the types shown, which read vehicle speed or engine speed directly (and thus function as conventional speedometers or tachometers) to simpler models having no driver readout whatsoever. Clock faces and a warning light, triggered when some critical vehicle parameter is exceeded, are also available. Internally, there is a multi-pen mechanism that records information on replaceable paper charts, either in circular or strip chart form, over time periods ranging from 8 hours to 31 days. The principal recording is a continuous analog record of engine or vehicle speed. Some models record both. The chart is driven by a clock mechanism, with preprinted identification of the time of day. Another parameter commonly recorded by a second pen within the unit is elapsed mileage or engine revolutions. Still another pen, sensitive to vehicle motion, records the period of time the vehicle is actually moving, which is usually used to flag excessive engine idling. Quite frequently, gross measurements of other parameters are also recorded. In this case, the parameter's sensor must supply a simple switch-closing indication when the desired parameter (e.g., vacuum, brake pressure, and exhaust temperature) exceeds a preset limit. The recording then indicates the switch opening and closing times by a step change in the pen position on the record.



(a)



(b)

Figure 4-16. Speedographs: (a) Typical Designs (Ref. 4-24), (b) Sample Chart (Ref. 4-25)

4.8.2 Specific Speedographs and Tachograph Devices

Speedographs and tachographs are available in a wide variety of styles, operating ranges, and features. The speedographs are easily installed in standard automobiles. Tachographs are somewhat more difficult to install because they require a mechanical drive for sensing engine speed. Adapters are available for this purpose.

The Sangamo Electric Company, Springfield, Illinois, markets a broad variety of speedographs and tachographs (Figure 4-17). Speedographs are available with ranges from 0 to 23, 45, 70, or 90 miles per hour, and 0 to 110 or 140 kilometers per hour. Tachographs have ranges from 0 to 1150, 2300, 2800, 3500, or 4600 revolutions per minute. The various ranges can be obtained in units recording 12 or 24 hours, or 8, 15 or 31 days (Figures 4-18 and 4-19), in either 12-volt or 24-volt models. Clock faces and speedometer or tachometer readouts are standard. Installation times are 2 to 3 hours for speedographs and 3 to 5 hours for tachographs (a mechanical engine speed drive must be installed). The list prices are $139 for 12- or 24-hour speedographs and tachographs, and $179 for 8-, 15-, and 31-day models. Add about $50 for tachometer drive.

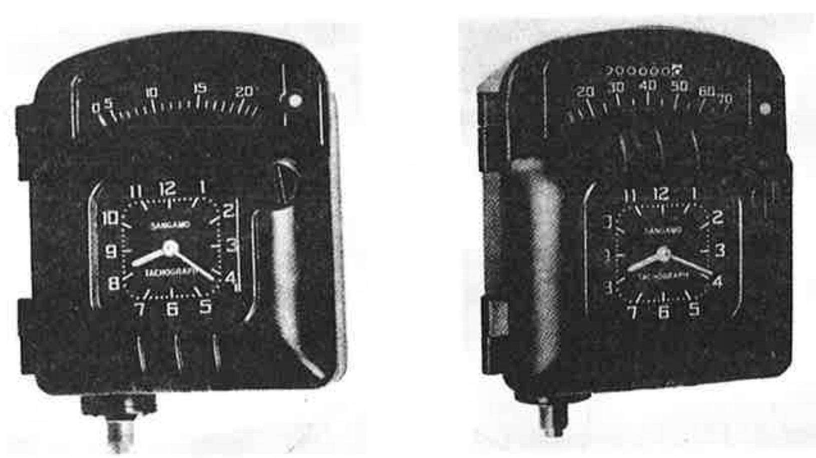


Figure 4-17. Typical Sangamo Tachographs and Speedographs (Ref. 4-26)

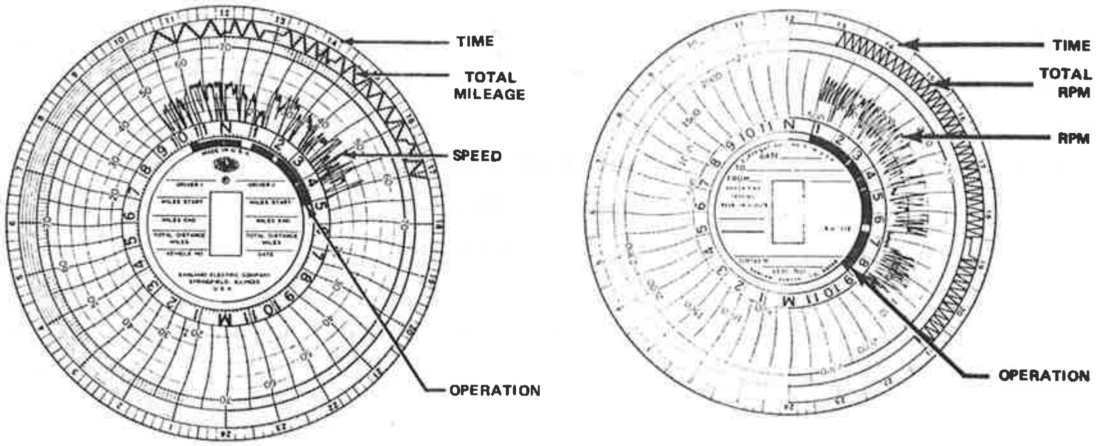


Figure 4-18. Typical 12- or 24-Hour Charts (Ref. 4-26)

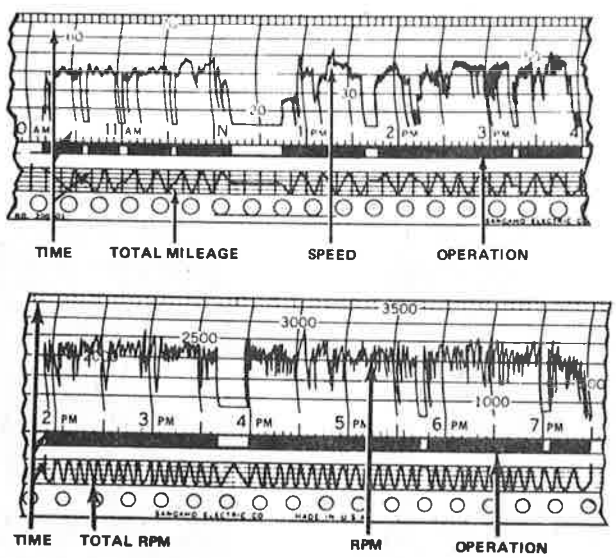


Figure 4-19. Typical 8-, 15, or 31-Day Charts (Ref. 4-26)

The Engler Instrument Company, Jersey City, New Jersey, and the Argo Instruments Corporation, Long Island, New Jersey, market similar lines of tachographs and speedographs. Models in these lines permit the simultaneous recording of both engine and vehicle speed on opposite sides of the chart. All recording is done on one-day circular charts, but a chart-changing mechanism permits recording up to seven days on seven separate charts. Speedometer and tachometer faces, or clock faces, are available. Installation time is the same as Sangamo above. The list prices are as follows: single function 24-hour, $195; single function 7-day, $223; dual function 24-hour, $307; and dual function 7-day, $322. Add about $50 for tachometer drive.

The Service Recorder Company, Cleveland, Ohio, markets tachographs and speedographs using 12-hour, 1-day, or 3-day circular charts. Ranges are from 0 to 70 or 110 miles per hour, or 0 to 3000 or 4500 revolutions per minute, with or without gage readout. Both the Service Company and the Argo Corporation also sell a simple recorder for about $89 that records only engine operation and vehicle motion. These devices are used to monitor the amount of useful work each vehicle performs and to identify excessively long periods of engine idling. One- and three-day versions are available. Installation is very easy; estimated time to install is 30 minutes or less.

Tachographs and speedographs are not sold as driver aids but rather as integral parts of driver education and training regimens. Therefore, specific numerical claims regarding fuel savings are not made. Data from the Douglas Aircraft Company Transportation Department suggest that a 19 percent savings in day-to-day operation might be achievable (Ref. 3-10).

4.9 THROTTLE POSITION DEVICES

4.9.1 Operating Principles

A throttle position device is simply a device that holds the throttle in a fixed position. Hand-operated throttles were standard equipment on most cars in the 1930's. On a level road the fixed throttle position will allow the car to maintain a constant speed. On upgrades the car will, of course, slow down and on downgrades it will speed up.

The potential fuel economy benefit of a throttle position device is that by holding the throttle in a constant position it prevents the small movements of the throttle normally made by most drivers. Thus it prevents the activation of the accelerator pump. Although there is some fuel economy benefit because of holding the throttle steady, it is estimated to be small. There is also some fuel economy benefit that derives from the fact that the vehicle will reduce speed on an upgrade. However, unless the driver releases the device at the top of the grade, it may be nullified, at least in part, by the overspeed that occurs on the downgrade. As with cruise controls, the throttle position device is useful only on the open highway or on lightly travelled freeways. Additionally, safety considerations require that an override be provided so that the throttle position device can be quickly deactivated in an emergency situation.

4.9.2 Specific Throttle Position Devices

Two typical throttle positioning devices available are listed in the J. C. Whitney and Co. Catalog (Ref. 4-27). The first is a standard hand throttle kit that is typical of the devices installed as standard equipment on automobiles in the 1930's. It sells for $2.49. A second is a electronic device that allows the driver to set the desired speed on a level road by pulling out a button on a box mounted on the dash board. The throttle can be released by touching the brake pedal. The driver can also override the device on an upgrade by pressing down on the accelerator. It is priced at $19.95.

Both units appear to be easy to install. Installation time should be as little as fifteen minutes for the hand throttle to as much as about one hour for the electronic throttle.

4.10 ACCELERATOR PEDAL FEEDBACK DEVICES

4.10.1 Operating Principles

An accelerator pedal feedback device is a device that directly resists or counteracts driver behavior which would lead to poor fuel economy. One such device that is available on the market is a mechanism for increasing pressure required to depress the accelerator pedal when the automobile approaches an operating region of poor fuel economy. As discussed in Section 4.1, as the load on the engine increases the vacuum level decreases. This change in vacuum level operates a mechanism that increases the pressure needed to depress the accelerator pedal.

The basic advantage of the accelerator pedal feedback device is that it does not have to be monitored. One problem with the actual design of such a device, however, is that the resistance required for satisfactory response and the force required to overcome this resistance may be quite different for various drivers of the car. Another difficulty with this device is its potential tendency to cause overshoot of the desired pedal position, with consequent additional and unnecessary consumption of fuel.

The throttle feedback device can be overridden; if the driver requires extra power he can further depress the accelerator pedal although it may require more pressure to do so. Again there is a potential problem area here since certain drivers may not be able to press the pedal as far or as fast as needed for satisfactory response in emergency accelerations such as sometimes required in passing maneuvers.

4.10.2 Specific Accelerator Pedal Feedback Devices

Tanner Electronics System Technology, Inc., Northridge, California, produces a throttle position feedback device called the TEST Gas Saver. The device is basically a vacuum-operated spring-loaded bellows. The bellows is connected to the throttle linkage by a flexible cable. When the engine vacuum is high the bellow is collapsed and does not offer any increased resistance to the accelerator pedal. As the engine vacuum decreases the bellows begins to expand. At low engine vacuum levels, the bellows is expanded enough to cause an appreciable increase in the required accelerator pedal pressure. The vacuum level at which the pedal pressure increases appreciably is adjustable. It is typically set at from 10 to 12 inches of mercury.

The retail price of the TEST Gas Saver is $29.95. Installation time is estimated to range from about one-half to one hour. The manufacturer of the TEST Gas Saver tested the device on seven automobiles and claimed to have achieved an average fuel economy improvement of 20.6 percent.

The U.S. Postal Service also evaluated the TEST Gas Saver (Ref. 4-28). The device was installed on five one-quarter-ton delivery trucks. The fuel consumption was monitored for approximately six weeks with the device and subsequently for six more weeks without the device to obtain a baseline. Another vehicle, which did not have the Gas Saver device installed for the entire period, was also monitored for the 12-week period. One vehicle with the TEST Gas Saver achieved a 5.1 percent mile-per-gallon increase. On the other four vehicles, decreases in fuel economy ranging from 2.3 percent to 25.3 percent were observed. The fuel economy of the baseline vehicle without the Gas Saver did not change.

As with other test results described in this section, it is difficult to draw firm conclusions from these results because neither the driver motivation nor the amount of instructions given to the driver was documented. It is possible that more favorable results could have been achieved by motivating the Postal Service drivers or by providing better instructions on how to use the device. Several of the drivers complained that they almost got into serious trouble because of the Gas Saver device. In some situations the drivers needed more vehicle acceleration and forgot that the device could be overridden.

4.11 AUTOMATIC CRUISE CONTROL DEVICES

4.11.1 Operating Principles

Cruise controls are devices that automatically manipulate the throttle to maintain a constant engine or vehicle speed. While not considered a driver aid device per se, since no information is output to the driver, cruise controls have been included here because they are offered as options by all four major car manufacturers, because they appear to be popular sales items, and because fuel economy claims have been made regarding their use.

There are four main components to a cruise control: (1) a speed sensor detecting either engine or vehicle speed, (2) a servo mechanism for changing throttle position in response to commands from (3) a "computer," and (4) a driver control. In operation, the desired speed is preset using the driver's control. This speed is then continually compared within the computer to the actual speed detected by the speed sensor. If the actual speed is different than that desired, the computer commands the servo to increase or decrease the throttle opening, as required. The control system usually remains active until switched off or until the brake pedal is touched. Use of the accelerator for higher speeds simply overrides the speed control until the driver's foot is again removed from the accelerator, when control reverts to the device.

Cruise controls have both advantages and disadvantages. The advantages include the ability to maintain a constant speed with relatively small, smoothly executed increments in throttle position. This improvement in speed control, plus the fact that the maximum legal speed limit can be maintained without inadvertent speeding, both contribute to fuel saving. An additional benefit found very desirable to those who use cruise controls is the reduced fatigue experienced on long trips when the driver is permitted to relax and move his legs about somewhat. The tension associated with observing the speed limit is also markedly reduced. These effects may also contribute indirectly to fuel economy improvement. The cruise control device was the only driver aid system that was given unanimous approval by representatives of all four domestic automobile manufacturers in discussions held in support of this study effort.

The disadvantages in using cruise controls as driver aids include the following. They are operable only above 30 miles per hour, are supplied only in vehicles with automatic transmissions, and are active only when traffic is sparse enough to permit constant speed operation. At these speeds and under these conditions, fuel economy problems are not usually severe. Another disadvantage of cruise controls is their complete insensitivity to load. This can result in wide-open throttle operation up long grades as the controller fights to maintain constant speed, resulting in significant fuel economy penalties.

4.11.2 Specific Cruise Control Devices

A large number of cruise controls are produced for original equipment applications, both by divisions of the auto makers and by independent companies. At least two models are available as retrofits (automatic transmission vehicles only). These models are described below.

The Perfect Circle Division of Dana Corporation, Toledo, Ohio, markets a vacuum-powered vehicle speed control (Figure 4-20) operated by a switch clamped to the turn signal stalk. In operation, the desired speed is first achieved manually. The "set speed" button is pressed, and speed is then automatically maintained by commands to a vacuum-powered bellows connected mechanically to the throttle. Actual speed is measured by a governor driven off the speedometer cable. The control is incapable of operating the engine at wide-open throttle when manifold vacuum falls very low because of the vacuum required to power the bellows actuator, which could produce some fuel savings under heavy loads since higher speed can not be maintained under those conditions. Operation of the controller using the stalk-mounted button does not require the driver to look away from the road, which is a safety benefit. The control is disenabled by braking or by switching off the unit. Installation time is 35 minutes to 4 hours, and the list price is $90.68 (Sears Catalog) to $111.95.

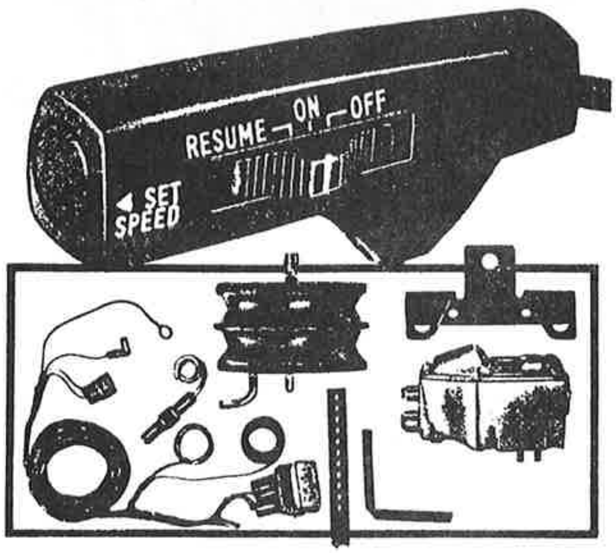


Figure 4-20. Dana Corporation Speedostat Cruise Control (Ref. 4-18)

Annuncionics, Inc., Los Angeles, California, markets an electrically powered engine speed control (Figure 4-21) operated by a control box mounted under the dash, within view of the driver. In operation, the control is turned on and enabled by a button on the control box. The engine speed is then controlled by an electrical motor attached to the throttle by a cable. The speed is preset by dialing the selector on the front of the control box to a number that corresponds to the desired road speed. The driver learns the relationship between the control numbers and vehicle speed by experience. Since it is actually engine speed that is controlled,

Figure 4-21. Annuncionics Pacesetter Cruise Control (Ref. 4-29)

some gas savings could result under heavy loads when slip in the automatic transmission increases. Actual road speed would then decrease at constant engine speed. Road speed variations are on the order of ±3 miles per hour. The control is disenabled by braking or by switching off the unit. The driver must visually set the desired speed-related number, which can be distracting. The dial is not lighted so that night operation is awkward. Installation time is one to three hours and the list price is $99.95.

The literature associated with cruise controls always implies fuel economy benefits but rarely mentions any specific numbers. Annuncionics is unique in its claims of 10 percent to 40 percent gas economy improvement. No supporting test data were found.

5. COMPARISON OF DRIVER AID DEVICES

5.1 EVALUATION CRITERIA FOR DRIVER AIDS

As noted in Section 4, fuel economy test data are available only for the manifold vacuum gage and the accelerator pedal active driver-feedback driver aid devices. Even in these cases, the tests are very limited and it is impossible to separate the effects of the aid device and any special driving instructions that may have been given to the drivers involved. These problems preclude a quantitative evaluation and comparison of the various driver aid devices. Therefore, the following evaluation criteria were selected for comparison purposes.

5.1.1 Technical Basis for Improving Fuel Economy

The first evaluation criterion is the relationship between the parameter sensed by the device (e.g., manifold pressure, acceleration rate, exhaust gas temperature, and vehicle speed) and the impact of monitoring this parameter on vehicle fuel consumption (as described in Section 3). In addition to this relationship, the adequacy of the accuracy of the device in monitoring the sensed parameter is also of potential importance.

5.1.2 Ability to Motivate Driver to Use Device

No matter how well and accurately the device monitors a fuel consumption-related parameter, the driver must respond to the output of the device in a timely manner in order to reap the potential benefits ascribed to the device in the technical sense. A second evaluation criterion, then, was the requirement levied on the car driver in monitoring the device, including inherent motivational features and training requirements in the use of the device.

5.1.3 Potential Effect on Driver Safety

Since personal safety is always of paramount concern, a third evaluation criterion selected was the potential impact of the device on safety, in terms of such problems as apparent distraction, time required to monitor the device, and device location.

5.1.4 Other Factors

The complex interactions of technical and human factors make any evaluation process approximate at best, and judgmental in nature, on an overall basis. In this study, the operational facets associated with human factors (e.g., habits and motivation) were treated only insofar as the technical character of the devices indicated that they would likely impact the car driver if he were properly motivated to use or take cognizance of the output of the device. Driver training, education, or other motivational techniques were assumed to be adequate to provide this degree of motivation. A general discussion of motivational factors and their impact is given in Section 6.

5.2 TECHNICAL BASIS FOR IMPROVING FUEL ECONOMY

Table 5-1 summarizes the more significant characteristics of the driver aid devices described in detail in Section 4. The fuel economy improvement claims noted in the table are those projected by the device manufacturer or promotor. As shown, the basic engine and vehicle parameters that are sensed, measured, or computed include the following:

a. Intake manifold vacuum (inches of mercury)
b. Vehicle speed (miles per hour)
c. Gasoline flow rate (gallons per hour)
d. Vehicle acceleration rate (g's)
e. Fuel economy (miles per gallon)
f. Exhaust gas temperature (degrees Fahrenheit)
g. Gasoline consumption per trip (gallons)
h. Throttle position
i. Variation of engine speed, distance traveled, vehicle motion, etc., with time
j. Engine air flow rate (cubic feet per minute).

TABLE 5-1. COMPARISON OF TECHNICAL CHARACTERISTICS

Class and Type of Device	Sensed Parameter(s)	Technical Adequacy (Basis for utility in improving fuel economy)	Claimed Fuel Economy Improvement (1)	Cost	Installation Time Requirements	Adequacy of Sensing Accuracy
o Manifold Vacuum Gages / Dial Readout, in. Hg / Color Range Readout / Multiple Colored Lights / Single Light (continuous or flashing) Dash-mounted Fender-mounted / Two-color Linear Piston Readout (2)	Intake Manifold Vacuum, in. Hg	Direct indication of throttle position and hence load and fuel consumption in relative terms. Objective is to drive to obtain highest manifold vacuum reading for a given driving condition. Vacuum readings below ~10 in. Hg indicate excessive acceleration or power. Principal advantage is to warn of excessive acceleration. A multi-color readout or multiple colored lights negate requirement to read vacuum value directly. Continuous or flashing light systems and two-color linear piston readout system are preset to warn the driver only when the vacuum falls below a predetermined level (~5.5 to 10 in. Hg range) and thus indicate only excessive vehicle acceleration or power.	10 to 25%	\$5 to \$35	15 to 90 min. (variation due to mounting placement and fittings required)	1. Generally adequate for parameter being measured. 2. Readings are sensitive to atmospheric pressure and altitude changes. 3. Dial readouts are constantly fluctuating with small changes in grade, etc., even with constant throttle position.
o Vehicle Speed Devices / Speed-warning Devices Red Light Audible Buzzer or siren Green, Amber, and Red Lights with Siren Flashing Turn Signals	Vehicle Speed, mph	These devices permit driver to pre-set unit to desired maximum speed level. Device warns driver (through lights, siren, etc.) when this speed is reached. Utility with respect to fuel economy limited to improvements associated with reducing vehicle maximum speed, providing driver heeds device warning signal.	Specific claims not always made. 21% to 36% has been claimed by some manufacturers.	\$10 to \$30	15 to 30 min.	Generally adequate for parameter being measured.

TABLE 5-1. COMPARISON OF TECHNICAL CHARACTERISTICS (Continued)

Class and Type of Device	Sensed Parameter(s)	Technical Adequacy (Basis for utility in improving fuel economy)	Claimed Fuel Economy Improvement(1)	Cost	Installation Time Requirements	Adequacy of Sensing Accuracy
o Fuel Flow Devices / Flowmeters	Gasoline Flow Rate, gal/hr	Flowmeters provide direct indication of rate at which fuel is being used. Driver could limit speeds and acceleration to more economical levels.	No specific claims.	\$50 to \$150	Not stated.	$\pm$ 2% accuracy claimed. Vapor bubbles, flow pulsations, voltage supply fluctuations, vibration, etc., can cause instrument errors.
/ Flow Totalizer	Total Gasoline Amount Used in Checked Interval, gallons	Totalizer would permit driver to compare speeds, driving routes, etc., as to total amount of fuel required and select best speed, route, etc., on this basis.		\$56 to \$119		
o Acceleration Devices / Accelerometers . Calibrated in g's . Green, Yellow, and Red Lights	Vehicle Acceleration Rate, g's	Accelerometers provide direct indication of vehicle acceleration rate. Driver could limit acceleration to more economical value. Colored lights indicate low, medium, and high acceleration rates.	No specific claims.	\$39 to \$139	30 to 60 min.	$\pm$ 3% accuracy claimed.
o Miles-per-Gallon (MPG) Meters / Dial Readout	Vehicle Fuel Economy, mpg, by measuring vehicle speed(mph) and fuel flow rate (gal/hr)	This device is the only device which provides a direct readout of vehicle fuel economy, mpg, during driving conditions. Driver could select vehicle speed to get better fuel economy. Driver would have to know basic speed vs. fuel economy relationship to appreciate MPG readings in lower portion of speed range (0 to 30 mph).	No specific claims.	\$39 to \$150	30 min. to 3 hr.	$\pm$ 3% accuracy claimed by one manufacturer. Tests by auto manufacturers have shown errors in -30% to +10% range. High absolute accuracy would not seem to be required if this is only used to show changes in fuel economy under various operating conditions.

TABLE 5-1. COMPARISON OF TECHNICAL CHARACTERISTICS (Continued)

Class and Type of Device	Sensed Parameter(s)	Technical Adequacy (Basis for utility in improving fuel economy)	Claimed Fuel Economy Improvement[(1)]	Cost	Installation Time Requirements	Adequacy of Sensing Accuracy
o Exhaust Manifold Temperature Devices / Pyrometers	Exhaust Gas Temperature	A band of acceptable temperatures, typically from 700°F to 1200°F, is established and the driver is instructed to remain within these limits. The minimum temperature limit warns of inefficient low-speed operation; the maximum warns of excessive engine loads. Use has been limited to commercial vehicle fleet drivers, most commonly in diesel engine applications.	No specific claims.	$72 to $184	2 to 4 hrs.	Adequate for parameter measured.
o Recording Devices / Speedographs / Tachographs	Continuous recording of engine speed, distance, vehicle motion, etc. vs. time base	Principal utility is to record driving behavior which can be used to illustrate driving deficiencies and constructively demonstrate where improvement is needed. Use has been limited to commercial vehicle fleets.	No specific claims.	$89 to $372	2 to 5 hrs.	Adequate for parameter measured.
o Throttle Position Devices / Mechanical Hand Throttle / Electronic Preset Device	Throttle Position	Permits driver to set desired speed on a level road, as with vehicle speed devices above, except here there is no warning system. Throttle can be released by touching brake pedal; device can be overridden by pressing down on accelerator. Utility with respect to fuel economy limited to improvements associated with reducing vehicle maximum speed or selecting optimum cruise speed.	No specific claims.	$2.50 to $20	15 min. to 1 hr.	Adequate for application.

TABLE 5-1. COMPARISON OF TECHNICAL CHARACTERISTICS (Continued)

Class and Type of Device	Sensed Parameter(s)	Technical Adequacy (Basis for utility in improving fuel economy)	Claimed Fuel Economy Improvement[1]	Cost	Installation Time Requirements	Adequacy of Sensing Accuracy
o Accelerator Pedal Feedback / Vacuum-operated Bellows on Throttle Linkage	Engine Manifold Vacuum	A vacuum operated bellows is connected to the throttle linkage. When vacuum is high the bellows is collapsed and does not offer increased resistance to accelerator pedal movement. At low engine vacuum levels, the bellows is expanded enough to cause an appreciable increase in required accelerator pedal pressure. This vacuum level is adjustable and typically set from 10 to 12 in. Hg. Thus the device tends to prevent pedal movements which would give high vehicle acceleration rates.	~ 20% claimed by manufacturer of 1 device.	$30	30 to 60 min.	Adequate for intended purpose.
o Cruise Controls / Vacuum-operated / Electronically Operated	Vehicle Speed, mph	Devices permit driver to preset desired cruising speed; device then automatically commands throttle position to maintain that speed. Utility with respect to fuel economy would be limited to improvements associated with selecting optimum cruise speed, reducing vehicle maximum speed, or maintaining constant vehicle speed.	Specific claims generally not made. One manufacturer claims 10% to 40% fuel economy improvement.	$90 to $112 (for add-on devices); available as OEM devices.	35 min. to 4 hours	Road-speed variations are on the order of ± 3 mph.
o Air Flow Rate Devices	Engine Air Flow Rate, cfm	Flowmeters provide direct indication of rate at which air is being consumed. Since air-fuel ratio is relatively constant for cruise conditions, driver could monitor air flow instead of fuel flow. Generally used for laboratory or research work only. Not offered as a driver aid.	No specific claims.	$50 to $592	Not stated.	Should be adequate for parameter measured.

[1] Values shown are those claims made by manufacturers of devices. Substantiating independent test data are not available.

[2] Also incorporates an audible warning of onset of over-acceleration.

These parameters are displayed and utilized to aid the driver in improving his fuel economy in four general categories:

a. Vehicle acceleration control
b. Vehicle deceleration control
c. Vehicle cruise speed control
d. Metering, route selection, and auxiliary functions

5.2.1 Vehicle Acceleration Control

The devices falling into this category include the following:

a. Manifold vacuum gages
b. Accelerator pedal feedback devices
c. Accelerometers
d. MPG meters
e. Pyrometers

The manifold vacuum gage provides a visual signal when excessive vehicle acceleration rates are imminent or in process, permitting the driver to reduce accelerator pedal pressure to remain within acceptable limits. The active driver-feedback device requires the driver to push harder on the accelerator pedal as vehicle acceleration rates increase, thus warning him directly by a physical force requirement that he is encountering excessive acceleration. Accelerometers directly measure and provide a visual readout of vehicle acceleration rate; the driver must therefore have knowledge of what acceptable g levels are. Similarly, pyrometers require detailed knowledge on the part of the driver as to the interrelationship of exhaust gas temperature and engine load and vehicle speed characteristics in order to utilize this device effectively to control vehicle acceleration. Merely scanning the pyrometer to assure that temperature levels are between predetermined high and low levels may, however, provide some combined measure of acceleration and steady-state speed control. The MPG meter, when used for acceleration control at low speeds, requires that the driver closely scan the instrument because of the normally low miles-per-gallon readings associated with the 0 to 30 mile-per-hour speed range of automobiles. This instrument more clearly conveys the fuel consumption effect of deceleration at the higher speed conditions.

5.2.2 Vehicle Deceleration Control

There is a single device in this category, the accelerometer, which measures deceleration rates as well as acceleration rates. Its principal utility would be to remind the driver to plan cruise speed in conjunction with existing traffic conditions to prevent the need for excessive vehicle deceleration by use of the engine and brakes. Again, the driver would have to know what acceptable deceleration rates are in order to benefit from the device readout.

5.2.3 Vehicle Cruise Speed Control

There are six devices having some applicability to this category. Three speed-limiting devices provide means of limiting top speed or selecting an economical cruise speed: (1) speed-warning devices, (2) throttle-position-setting devices, and (3) automatic cruise controls. The MPG meter, by providing a direct readout of fuel economy, could, in combination with speedometer scanning, enable a driver to select an optimum cruise speed (traffic permitting). The manifold vacuum gage (with a dial readout) can provide an indication of when uneconomical higher vehicle speed operation is encountered by virtue of the drop in manifold vacuum that occurs. This drop is very gradual, however, and may have to be monitored too closely to be of significant cruise control value to most drivers. Gage readout variations caused by grade changes, for example, further detract from this capability of the vacuum gage. The pyrometer, as mentioned under Acceleration Control (Section 5.2.1), could provide guidance for avoidance of uneconomical high-speed, high-load operation.

5.2.4 Metering, Route Selection, and Auxiliary Functions

The last category is comprised of six devices. Fuel and air flowmeters provide a direct readout of fuel and air consumption at any given driving condition, but require comparative knowledge on the part of the driver in order to change driving conditions to reduce fuel consumption. Fuel totalizers provide no direct input during driving, but permit the driver to maintain comparative records of fuel consumed over different routes. Similarly, speedographs and tachographs record trip pattern data and driving behavior for later use in illustrating driving deficiencies. The fuel totalizer plus trip pattern data from speedographs or tachographs could be used to determine the effect of trip length and driving pattern on fuel economy. While not explicitly measured, the effects of idling time and cold-start conditions on fuel economy could be determined if routes being compared were consistently defined and controlled in terms of these variables. The MPG meter, as mentioned above in Section 5.2.3, is potentially useful in providing a direct readout of fuel economy; initial use of this device requires scanning in combination with the speedometer to select economical cruise speed conditions.

5.2.5 Efficacy of Devices

The efficacy of any of these devices with regard to aiding the driver to improve his fuel economy, would, of course, depend on the specific driver, his normal driving patterns or routes, and the degree to which he is motivated to use a particular device. There is not sufficient comparative test data to evaluate these interrelationships for even a single such device at this time. Until such data are available, specific fuel economy improvement claims sould be viewed with caution.

5.3 DRIVER REQUIREMENTS AND SAFETY IMPLICATIONS

The driver must respond to the output of a device in a timely manner in order to reap the potential benefits ascribed to the device in the technical sense. Table 5-2 summarizes the more significant requirements levied

TABLE 5-2. COMPARISON OF DRIVER REQUIREMENTS AND OTHER FACTORS

Class and Type of Device	Requirements Levied on Driver In Order to Use Device (1)	Possible Safety Implications (1)	Other Factors
o Manifold Vacuum Gages / Dial Readout, in. Hg / Color Range Readout / Multiple Colored Lights / Single Light (Flashing or Continuous) Dash-mounted Fender-mounted / Two-color Linear Piston Readout	1. In the case of dial readouts, the driver merely needs to know that he should attempt to obtain the highest vacuum reading or the color indicated as acceptable or best for fuel economy. Because these dial indicators are constantly fluctuating, the driver may also need to know why this happens in order that he may properly respond. 2. The use of multiple colored lights relieves the fluctuating dial problem somewhat. 3. The use of single lights or the two-color linear piston readout merely requires that the driver be aware that the condition being warned against is excessive vehicle acceleration.	1. A driver attempting to pay too much attention to a dial readout device may be distracted from safe driving habits. Placement of the dial for ease of scanning could help this situation, but not eliminate the possibility. 2. The use of lights (flashing or continuous) would appear to require less visual concentration on the part of the driver and enhance his ability to drive safely. Some drivers have reported they felt a flashing light was a possible safety hazard, but have not stated why they felt that way. 3. Other drivers have reported that they felt the two-color linear piston readout device was distracting and could possibly cause accidents. More recent models of linear piston device incorporate an audible characteristic to warn of the onset of over-acceleration.	Dial readout gage could be used by motorist for monitoring the condition of the engine.
o Vehicle Speed Devices / Speed Warning Devices Red Light Audible Buzzer or Siren Green, Amber, and Red Lights with Siren Flashing Turn Signals	Driver merely needs to know his desired maximum speed, whether for fuel economy, staying within posted speed limits, etc.	Sudden buzzer or siren sounds could be distracting to some motorists. As noted above, flashing lights, etc., could be also distracting.	

TABLE 5-2. COMPARISON OF DRIVER REQUIREMENTS AND OTHER FACTORS (Continued)

Class and Type of Device	Requirements Levied on Driver In Order to Use Device[1]	Possible Safety Implications[1]	Other Factors
o Fuel Flow Devices / Flowmeters / Flow Totalizer	Use of flowmeter to identify more economical speeds and accelerations requires scanning of device readout. Use of totalizer merely requires reading indicator at end of trip and resetting for next trip.	Flowmeter scanning of a continuous nature could distract driver from safe driving habits. Readout of totalizer occurs after vehicle is stopped and should not impact safety in any way.	
o Acceleration Devices /Accelerometers Calibrated in g's Green, Yellow, and Red Lights	Use of an accelerometer calibrated in g's requires scanning of the device readout as well as some knowledge of g levels associated with improved fuel economy. Units with colored lights would not require special knowledge of g levels, and would require less visual attention.	Accelerometer scanning of a continuous nature could distract driver from safe driving habits. Colored lights, changing sequence, could also distract drivers.	
o Miles-per-Gallon (MPG) Meters / Dial Readout	The driver is only required to be able to read the dial gage and recognize that the best fuel economy occurs with the higher mpg numbers. Since low vehicle speeds give poor mpg, the driver should be acquainted with speed versus fuel economy characteristics in order that he not be confused by varying mpg readings.	MPG meter scanning of a continuous nature could distract the driver from safe driving habits.	
o Exhaust Manifold Temperature Devices / Pyrometers	The driver only needs to know what the acceptable temperature limits are and what to do at the extreme limits (e.g., increase speed and load at low temperatures and decrease speed and load at the high temperature)	Constant scanning of the pyrometer readout could distract the driver from safe driving habits.	

TABLE 5-2. COMPARISON OF DRIVER REQUIREMENTS AND OTHER FACTORS (Continued)

Class and Type of Device	Requirements Levied on Driver In Order to Use Device(1)	Possible Safety Implications(1)	Other Factors
o Recording Devices / Speedograph / Tachograph	Driver is not involved with use of these devices.	None	
o Throttle Position Devices / Mechanical Hand Throttle / Electronic Preset Device	The driver merely needs to know the speed that is best for economical operation, and how to set the specific device.	Should be no significant safety implication for electronic preset device since the device is released by touching brake pedal or pressing down on accelerator pedal. However, the driver could be lulled into an inattentive condition since he may not constantly be monitoring pedal position, and this could create a safety hazard.(2)	
o Accelcrator Pedal Feedback / Vacuum-operated Bellows on Throttle Linkage	Here, the driver only needs to know that high pedal pressures mean poor fuel economy and that, where possible, he should not get into those driving situations demanding high pedal pressure. He does need to know that the device can be overridden in those instances where increased acceleration or speed is required.	Some drivers have complained that they nearly got into serious safety problems with this type of device. Apparently, they needed more vehicle acceleration and forgot that the device could be overridden, or were unable to do so.	
o Cruise Controls / Vacuum-operated / Electronically Operated	Here, the driver only needs to know acceptable values of cruising speed which give good fuel economy, and how to set the specific device.	Same as remarks for throttle position devices, above. On the other hand, it is postulated that the driver may be more attentive because he can move his foot about, be more comfortable, etc.	

TABLE 5-2. COMPARISON OF DRIVER REQUIREMENTS AND OTHER FACTORS (Continued)

Class and Type of Device	Requirements Levied on Driver In Order to Use Device(1)	Possible Safety Implications(1)	Other Factors
o Air Flow Rate Devices	Use of flowmeter to identify more economical speeds and accelerations requires scanning of device readout.	Flowmeter scanning of a continuous nature could distract driver from safe driving habits.	

(1)Any device requiring scanning, or any audio or visual signal, can be hypothesized to cause some degree of distraction to the driver. This indicates a training requirement for the driver, in order that he be able to use the device with minimum impact on his normal driving techniques relative to road safety.

(2)Mechanical hand throttle requires coordinated hand and foot action for throttle release and braking; may confuse driver and delay or impair emergency deceleration maneuver.

on the driver in this regard, as well as possible safety implications arising from this interaction of driver and device. As indicated, the basic requirements levied on the driver fall into four general categories:

a. Visual scanning
b. Response to discrete signals
c. Knowledge of effect of change
d. Preplanning, presetting, and resetting

5.3.1 Visual Scanning

Those devices requiring visual scanning include the following:

a. Dial readout vacuum gages (inches of mercury or colored zones)
b. Two-color linear piston vacuum gage
c. Fuel and air flowmeters
d. Accelerometers (calibrated in g's or with colored lights)
e. MPG meters
f. Pyrometers

The degree or amount of scanning required to utilize the output of the device effectively is not quantified for any of these devices. It would be expected to vary from driver to driver as a function of perceptiveness, peripheral vision acuity, and general ability to correlate simultaneously the many variables encountered during normal driving encounter situations. Where the driver would be required to focus too much attention on the readout, it could definitely affect driving safety. Device placement, size, and readability, for example, would be enhancement factors, but would not be totally determinative of safety implications. Driver training in the use of any such device may be a requirement to mitigate the potential for excessive scanning and its impact on traffic safety.

5.3.2 Response to Discrete Signals

Some devices merely require the driver to respond to a visual, audio, or physical signal. Vacuum gages with lights (instead of dial readouts) and speed warning devices with lights require the driver to perceive that the light has come on. The degree of attention required to perceive the light or the potential distraction caused by the light, again is not quantified and would be expected to vary from driver to driver, as noted above in the case of visual scanning. Audio speed warning devices involve no visual perception and thus involve only a potential distraction to the driver when the signal comes on. The vacuum-operated accelerator pedal feedback device provides a physical signal to the foot of the driver in response to his acceleration demand signal. The driver must push harder to override the device when he truly needs acceleration in excess of that required for fuel-efficient operation. The safety implication of this device is that the driver must be aware of and be physically able to exercise this override capability in order to respond to traffic flow demands. In all cases, as in the case of the visual scanning requirement above, driver training may be a requirement to minimize possible adverse safety effects.

5.3.3 Knowledge of Effect of Change

All the devices in Section 5.3.1 above require, in addition to visual scanning, some knowledge of the effect on fuel economy of changes in the parameter being displayed in order to be fully utilized by the driver. Thus, they also impose the additional need for the driver to recall stored characteristics information in combination with visual scanning in order to respond most effectively to the full capability of the device. For example, if the vacuum gage were being used to select a good cruising speed, much more scanning attention would be required than for a simple indication of when low manifold vacuum (excessive acceleration or power) was taking place. The safety implications of more intensive scanning, combined with recall and judgment on the part of the driver in the area of driver safety, are thus more serious than as discussed above for casual scanning only.

5.3.4 Preplanning, Presetting, or Resetting

Finally, there is the group of devices that require preplanning, presetting, or resetting. They include the following:

a. Fuel totalizer
b. Speedograph
c. Tachograph
d. Throttle-position-setting devices
e. Automatic cruise controls

In general, these devices either are not operated by the driver during driving or require minimum efforts on the part of the driver. Thus, they should have minimal impact on safety, per se, unless a given device has complicating or distracting setting or resetting processes.

Automatic cruise controls are becoming quite popular as new car equipment and are reported to have benefits in terms of driver fatigue, which is postulated to improve driver safety since the driver is more alert.

5.4 APPLICATION SUMMARY

Table 5-3 summarizes the areas of application for the driver aid devices previously described in the principal utility areas of acceleration and cruise speed control.

Those devices affording some measure of acceleration control include the vacuum gage, MPG meter, accelerator pedal feedback system, accelerometer, pyrometer, and fuel and air flowmeters. The MPG meter and the fuel and air flowmeter capability is considered limited because of the need to scan the instrument carefully in order to determine variations in readings. The capability of the pyrometer is considered limited because of poor correlation between exhaust gas temperature and fuel consumption rates under various driving conditions.

Those devices affording economical cruise speed control include the MPG meter, throttle position devices, automatic cruise controls, and

TABLE 5-3. DRIVER AID DEVICES—AREAS OF APPLICATION SUMMARY

Class and Type of Device	Areas of Application		
	Acceleration Control	Cruise Control	Other
Manifold Vacuum Gages			
Dial and Color Range Readouts, Multiple Colored Lights	Yes	Yes (limited)	Dial readout can indicate engine condition
Single Light, Two-Color Linear Piston	Yes	No	
MPG Meter	Yes (limited)	Yes	
Accelerator Pedal Feedback	Yes	No	
Accelerometer	Yes	No	
Pyrometer	Yes (limited)	Yes (limited)	
Speed Warning Devices	No	Yes (limited)	
Throttle Position Devices	No	Yes	
Automatic Cruise Controls	No	Yes	
Fuel Flowmeter	Yes (limited)	Yes	
Fuel Totalizer	No	No	Record-keeping of fuel used; comparisons and route selections
Speedographs and Tachographs	No	No	Driver training aid
Air Flow Rate Devices	Yes (limited)	Yes	

the fuel and air flowmeters. The pyrometer, speed warning devices, and most vacuum gages also offer the potential for limited cruise control.

The fuel totalizer and speedographs and tachographs do not offer direct control in either of these areas. The totalizer's value lies in record-keeping and comparison functions, including route selections. Speedographs and tachographs may be extremely valuable as driver training aids.

6. DRIVER ATTITUDE AND MOTIVATION

The single most important factor in the efficacy of a driver aid device is the driver himself. The ultimate objective of the driver aid device is to cause a persistent real-time alteration of each individual's personal driving habits, habits that have become ingrained and reinforced over years of driving experience. Moreover, to be of value, the magnitude of these changes must be significant, and their effect must be sustained permanently. In order to accomplish these objectives, fundamental changes in the mental attitude of the driver will be necessary. The key to such changes is motivation, either as supplied from within the driver himself, as developed through training or education, or as provided directly from the device. Regardless of its source, it is human motivation, and the relative success with which it is engendered, that will determine the success or failure of the driver aid device.

6.1 DRIVER AIDS VERSUS CONVENTIONAL INSTRUMENTS

One might contend that the driver aid device is simply one more gage or light on a panel filled with gages and lights and that, because of this physical similarity, a functional or operational similarity also exists. In fact, the driver aid device is completely unlike any other device on the vehicle, for four reasons: familiarity, frequency of use, inherent self-motivation and, most importantly, the desired level of influence over driver habits.

Consider the six devices on the conventional instrument panel: speedometer, odometer; oil pressure, water temperature, and battery charge and discharge displays; and fuel level indicator. Each of these is familiar to the average driver. He may not understand the operation of the devices, but he does know how to interpret and apply their output. Driver aids, on the other hand, are uncommon. The driver must be told what they are, why they are there, and how they are to be used.

The frequency-of-use aspect is also considerably different. The odometer is almost never used, and the same holds true for the oil pressure, water temperature, and battery displays. The fuel level gage is sometimes ignored for days at a time. Only the speedometer is referred to on anything approaching a continuous basis. When use of the instruments is infrequent, tedium is not a serious problem. However, when the driver attempts to maintain a constant 55 miles per hour over a long period of time, for example, the strain may be tiring. Effective use of many driver aids demands just such a constant level of attention, not only on the highway but at all speeds, and particularly during poor-economy city driving when the driver's attention is much more urgently needed elsewhere. This sustained level of concentration, if achieved, can be inconvenient, uncomfortable, distracting, and even dangerous.

The inherent self-motivation of the standard dashboard instrumentation is, for the most, fear. If the oil pressure or water temperature lights come on, the driver knows that the engine may be damaged should the problem not be corrected. Most drivers are also afraid of having the car run out of gasoline far away from a gas station, or of not having it start in the morning. This visceral concern on the part of the motorist for the loss of money or convenience supplies a natural motivation to use the oil, water, and battery indicators, and the fuel gage. The speedometer receives deliberate attention when a concern about legality or safety is aroused. At most other times, interest in both the speedometer and odometer is only casual. The driver aid device, on the other hand, generally must rely on the driver's interest in money savings accumulated in small increments. Since the dollar savings are small over any short period of time, fear is not useful as a motivator in the same sense as with the oil pressure gage, for example, where a one-time loss of several hundred dollars is involved. It is the very subtleness of the benefits achieved with the driver aid that necessitates a much higher level of motivation.

The last and most significant difference between conventional instruments and driver aids is the level of control that is sought over driver behavior. None of the standard instruments require the driver to make any change in his driving techniques, with the possible exception of not speeding. The driver aid, however, is actually designed to pass judgment on long-held and even cherished driving habits, and then to remind the driver to modify his habits in the interest of improved fuel economy. The amount of motivation needed to change any personal habit is large, and driver aids are no exception to this fact.

6.2 HISTORICAL USE OF DRIVER AIDS

One obvious cause for concern about motivation to use driver aids is the fact that, while driver aids have existed for decades in various forms as fuel economy aids, they have never been accepted as an integral part of motor vehicles. For over 40 years, the standard automotive instrumentation set has consisted of only six devices. During that entire period of time, the potential benefits of driver aids in the form of vacuum gages were known to the industry, and their use was advertised to the public in connection with such contests as the Mobilgas Economy Run. Yet they never became part of the car's instrumentation, even in countries outside the United States where gas prices and fuel economy were historically a major consideration.

Several interrelated factors apparently led to the nonuse of driver aid devices. First, no broad public demand for the devices ever materialized. Perhaps the public wasn't sufficiently motivated to save gas, or perhaps they failed to comprehend the potential of such devices as it related to their personal driving. It is also likely that most drivers remained completely unaware of such devices. Regardless of the reasons, the automobile manufacturers never perceived sufficiently strong consumer interest to warrant the addition of driver aids. Without some indication of consumer demand, auto makers were never motivated toward the extensive marketing effort that would have been necessary to evaluate the actual extent of driver acceptability and benefit.

The automobile manufacturers began to consider driver aids with new intensity in the early 1970s because of the projected decline in fuel economy caused by safety and pollution mandates. OPEC's creation, the oil embargo, and the subsequent price increase of gasoline provided the final impetus. Based on the assumption that driver aids might meet with broad public support under these new conditions, vacuum devices were made available on several MY '74 models. This was extended in MY '75 to include vacuum-driven gage or light devices on all AMC, Chrysler, Ford, and General Motors cars. As yet, Detroit does not know how well customers have received the devices; no after-sales surveys have been carried out.

6.3 INSTRUCTION AND MOTIVATION

A clear-cut delineation should be made between the two potential, and quite distinct, benefits that can be sought from driver aid devices: instruction and motivation. The device can instruct in the sense that the displayed information tells the driver what corrective action to take to improve his driving performance. This information has maximum value when it can be applied in real-time or near real-time. The vacuum gage performs this function. If the vacuum is sufficiently high, the driver is to do nothing. When the vacuum falls too low, the driver is to back off on the accelerator.

A device can also motivate in the sense that it can engender in the driver the desire to alter his driving habits in some beneficial manner. It is far more difficult to define any particular device as being purely motivational, simply because so little is known about driver motivation. However, the vacuum gage can again be used for discussion, this time as a device that is not motivational. That is to say, a vacuum gage tells the driver what to do but not why to do it. In this case, the reason for monitoring the gage and for following its instructions must come from sources other than the vacuum gage itself. This motivation usually stems from a desire to conserve gas and money, coupled with both the knowledge and the appreciation that, by following the dictates of the vacuum gage, this desire can be satisfied.

It is important to stress the "appreciation" aspect of the education associated with instructional-type devices. One of the reservations most frequently expressed about the use of vacuum gages, for example, speaks directly to this issue. It is relatively easy to explain the proper use of a vacuum gage and to communicate the concept that "high vacuum" is related to good economy, while "low vacuum" equates to poor economy. What is almost impossible to explain is just how much benefit, in either gallons or dollars, the user can expect to achieve.

The average user of a vacuum gage does so more out of a belief that it saves gas rather than from any quantitative knowledge that it does. The only exceptions are those individuals who painstakingly collect sufficient data to define the savings, and very few individuals are that strongly motivated. Therefore, if the driver's interest in an instructional device is to be sustained over a long period of time, he must have some way of appreciating the magnitude of the benefits he is achieving, as well as simply knowing that the device is somehow related to economy.

It is possible to achieve some degree of both motivation and instruction from the same device. In order to expand on this concept, three different devices will now be discussed. These are defined, as accurately as the topic allows, as instructional, motivational, and combined instructional and motivational. The vacuum gage is an example of an instructional device. It tells what to do but not why to do it.

An example of a device that is purely motivational is a fuel totalizer, calibrated to consider the local price of gasoline and reading directly in dollars and cents. The housewife can now zero the device before leaving for the store. When she returns, the actual dollar cost of her shopping trip is displayed in language she cannot fail to appreciate. The dollar totalizer has thus provided the motivation necessary to ensure cooperation with an instructional device, but it has not provided any actual instruction in driving habits per se. Even here, however, the distinction between motivation and instruction is blurred, because the totalizer may produce direct gas savings by convincing the housewife to drive less.

A device that falls in the combined instructional and motivational class is the miles-per-gallon, or MPG, meter. Here, a real-time readout of miles per gallon is provided, in the hope that this parameter is sufficiently familiar to the driver to provide some motivation, since the relationship between MPG and dollar cost is assumed to be fairly well appreciated. It also has some instructional aspects, since intelligent manipulation of the cruise speed can maximize the miles-per-gallon economy of the trip. Unfortunately, the MPG meter is somewhat deficient in both motivation and instruction. Motivation is decreased because the ultimate objective, assuming it is dollar savings, is not explicitly indicated.[1] Also, the instruction potential has been reduced, because the specific best-response action for the driver is not explicit either. He may have to speed up or slow down, depending on his speed at the time. The MPG gage only indicates, a posteriori, whether or not he has chosen correctly.

Almost no information exists on the optimum device or combination of devices necessary to achieve significant savings, but that which does exist comes predominantly from experience with driver aids in fleet vehicle applications. In these examples two or more devices are invariably required for success, one for motivation and one or more for instruction. Instruction is usually provided by devices such as vacuum gages or pyrometers, or by the speedometer or tachometer. Training sessions are held to acquaint the drivers with the characteristics of the devices, and to establish rules regarding acceptable operation of company vehicles as reflected in these devices (such as simply observing posted speed limits).

In institutional applications, most of the motivators that apply to the private car owner are missing. The fleet driver neither owns the vehicle, nor does he pay for the gas. His unconstrained motivation is generally personal convenience, which is not necessarily synonymous with good fuel economy. Therefore, recording devices (see Section 4.8, Speedographs and

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[1] Such meters could be designed to display a dollars-per-mile readout; current MPG meters do not incorporate this feature.

Tachographs) are installed that create a permanent record of the operation of the vehicle every minute of the day. This tamper-proof record is then reviewed with each driver, and steps are suggested for maintaining compliance with the rules. This close supervision supplies the necessary driver motivation. It has an additional advantage in that even self-motivated drivers do not always appreciate the techniques necessary to conform to the company's rules. The follow-up sessions provide an opportunity to relate the methods for conforming to those rules with the driver's individual habit patterns. Failure to comply generally results in the driver being returned to the classroom for additional instruction. The embarrassment attached to the need for retraining is also a strong motivator. Flagrant or persistent noncompliance usually leads to dismissal. One final advantage of using the recording devices, from the employer's viewpoint, is that these permanent records have been used quite successfully to substantiate legal vehicle operation in accident-related court actions.

Any driver aid selection must consider both instruction and motivation. However, considerations such as cost, type of training, driver skill, and safety must also be included. The selection process is complex, particularly with private car devices where almost no guidelines are available.

7. FACTORS TO BE CONSIDERED IN A DOT EVALUATION PROGRAM

7.1 OBJECTIVES

In broad terms, the goal of a field test in this program is the evaluation of the effectiveness of specific driver aid devices in increasing vehicle fuel economy. This general goal can be divided into two major objectives:

a. Determine if a driver aid device, when monitored, will help a typical driver to achieve better fuel economy. Before any test program involving driver aid devices begins, base-line fuel economy values must be established and the potential drivers must be given instructions both on methods of driving to improve their fuel economy and also on the use of the device. Therefore, in order to satisfy this objective, it must be determined how much of the fuel economy increase resulted from the training program itself and how much from the actual use of the device.

b. Determine if drivers will continue to drive in an economical manner and to monitor the driver aid devices for an extended period of time or if instead they will revert to their old driving habits and ignore the driver aid device. As a subob-jective, it must be determined if a driver will monitor a gage or whether he will respond better to audio or visual alarms that do not require his continual attention.

The first objective includes the separation of the fuel economy improvement owing to driver training and to the use of the driver aid device. The separation of these effects is important for two reasons. First, there is little disagreement that driver training alone can result in improved fuel economy (see Section 3). Second, the results of a limited test by Mobil Oil (Section 3) indicated that the fuel economy improvement resulting from training was not significantly improved when a driver aid was added. If this result proves to be generally true, then the primary function of a driver aid device may be to remind the driver when he begins to revert to his old driving habits and to motivate the driver to drive economically.

A possible additional test objective is to determine which device or combination of devices provides the best improvement in fuel economy. In order to satisfy this objective, multiple comparative tests must be performed.

The testing program could involve two different test groups, one involving the general driving public and the other involving fleet vehicles with professional drivers. The basic difference is motivation. The average person driving his own personal vehicle must pay for the gasoline he consumes, and reduced fuel costs may provide the necessary motivation. On the other hand, since the fleet vehicle driver does not pay for the fuel he uses, other means must be found to motivate him (see Section 6, Driver Attitude and Motivation).

7.2 IMPORTANT CONSIDERATIONS

7.2.1 Experimental Contamination

The importance of a field test involving cars and drivers operating under normal conditions can be appreciated by realizing the relationship between the automobile, the operator, and the device. It is not the device that creates greater fuel economy, but rather the driver, who acts upon the automobile according to cues provided to him by the device. The device, in turn, produces cues based upon measurements of the automobile's state. The relationship is briefly sketched in Figure 7-1.

The object of this study may be viewed as follows: to evaluate the efficacy of the device in influencing the driver where the efficacy is measured through parameters produced by the automobile. The point of this is to provide a structure within which to assign the sources of contamination resident in the field test. The central quest is to determine the extent to which a general driver can (or will) reduce his fuel consumption, as defined for a general vehicle, in response to cues provided by a specific driver aid device. However, the actual fuel consumption in any time interval is influenced by many factors other than the one, device efficacy, being studied. Furthermore, many of these contaminating factors fluctuate in time and are not constant from driver to driver or from vehicle to vehicle. Examples of driver-related contamination include variations in driving techniques, the

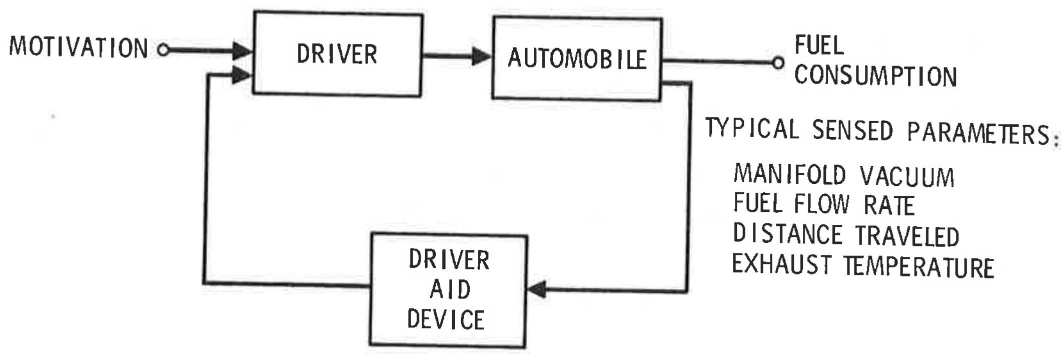

Figure 7-1. Driver-Device-Vehicle Relationship

distribution of trip lengths, and passenger loading. Examples of vehicle-related contamination include mechanical state of tune and physical characteristics, such as weight, engine size, and transmission type. These contaminating factors, or variables, must be controlled out of the experiment so that a meaningful assessment of device efficacy can be made. Device efficacy will be dependent upon not only overt characteristics such as parameter presented and presentation format but also covert characteristics such as the driver's attitude toward the device.

Another contaminant to be considered in the experiment design for the field test is the presence of the classical Hawthorne effect. It is likely that the consciousness of the drivers that they are participating in a test and are being monitored and measured will alter their driving characteristics, and hence their fuel consumption, independently of the device efficacy. Ideally the participants would be completely unaware of their participation in the test. However, this would render acquisition of mileage, fuel consumption, and other necessary data nearly hopeless. Emphasis must therefore be placed on acquisition of the data in the least obtrusive manner possible. Consideration should be given to credit receipt monitoring (which might miss cash purchases) and sealed counters in the vehicles, for example.

7.2.2 Test Groups

Consideration of the difficulties involved in data acquisition introduces the subject of test group definition. Various types of test groups can be envisioned, and these roughly ranked in order of the tightness with which an experiment involving each can be controlled. At the extreme of tight control is a fleet situation in which the vehicles are uniform, maintenance is performed on a strict schedule, vehicle inspection is a matter of course, route assignments are fairly uniform, and the population of drivers changes very slowly. However, ingredients likely to be missing in the fleet scenario are motivation prompted by economic self-interest and attitudinal measures related to device cost. At the extreme of loose control is the general driving public, driving a wide variety of vehicles in various states of tune under various driving conditions. Performance data will be difficult to obtain without affecting driver attitudes and performance, and permanence of the participant group cannot be ensured. The general public group, with its inherently larger number of uncontrollable variables and hence greater variability, will require longer test periods and a larger number of participants and vehicles to reach definitive conclusions regarding device efficacy with the same precision and confidence as for the more tightly controllable groups.

7.2.3 Sample Sizes

A critical consideration in any experiment design is the selection of sample sizes. In the present case, sample size refers to the number of vehicles monitored, the number of drivers participating, the number of parameters measured, the frequency of measurement, and the duration of the test. The central question in sample size determination is how many measurements are needed to distinguish reliably between the presence of a systematic factor, e.g., a genuine increase in gas mileage, and the operation of variable or random chance events, e.g., the beginning of summer with its associated incidence of vacation trips. The major problem in predetermining test sample sizes is the lack of an estimate of the variance associated with the test parameters. Roughly speaking, the sample size and the background variability combine to yield the significance level or statistical confidence that may be ascribed to the test results. In the absence of reliable variance estimates, one can specify either the test confidence or the sample size but not both. If a certain confidence level is specified, the sample size (test duration and scope) and, hence, the test cost are undetermined. In specifying the sample size, usually through a limit on cost, the test confidence remains unknown until the test is at least partially complete. The way out of this dilemma is to perform a pilot test phase of limited scope in which the major objective is to obtain estimates of the variabilities associated with the various test parameters.

As an example of the above discussion, consider the case of a Gaussian population with variance σ^2 in which it is desired to determine if there has been a shift in the average value between two time periods. The width of the confidence interval based on M and N measurements in the two periods (e.g., before and after driver training) is given by

$$W = 2k_\gamma \sigma \sqrt{\frac{1}{M} + \frac{1}{N}}$$

where γ is the confidence level associated with the confidence interval, and k_γ is a monotonic function of γ. The confidence interval describes the interval of values within which the shift will lie with confidence γ. Thus, the interval width W is an inverse measure of the precision of the test. For a fixed precision requirement and test confidence, the required sample size must vary as approximately σ^2. Or, put another way, for a fixed sample size, if the variance is larger than expected the precision will be poorer, or the confidence level lower.

7.2.4 Hazard Analysis

Inherent in the driver aid device concept is the expectation that the vehicle operator will monitor the device output on a more or less continuous basis in order to optimize his driving strategy. In an amount depending upon the presentation format of the device, the operator's attention will be partially diverted from the driving itself, as indeed it presently is by speedometers, radios, cigarette lighters, and other accessories. In addition it is anticipated that certain standard driving patterns will be altered in response to the device output. For example, a new driving strategy may emerge in which the driver, possibly even shifting into neutral, allows the vehicle to coast when he perceives a distant red light. A careful examination of the impact of factors such as diverted attention and altered patterns must be performed to determine if such devices, while perhaps enabling a fuel savings, increase the risks associated with driving.

7.3 EVALUATION PHASES

The evaluation of the driver aid devices can proceed in a three-stage process: detailed test design, pilot testing, and field evaluation.

a. The detailed test design would consist of final specification of test objectives, quantification of objectives to yield statistical tests, definition of data requirements, and planning for execution of the test.

b. The pilot test phase would be designed to determine unforeseen problems and would also yield preliminary estimates of variance associated with the test variables that have been identified in the design phase. At the completion of the phase an assessment would be made of the probability of successful device evaluation within the constraints of available time and resources.

c. The final test phase would consist of the field evaluation conducted in those secenarios and under those conditions identified in the first two phases.

7.3.1 Test Design

Before the test design effort can begin, the test objectives must be formulated. Details of the test objectives may be modified during the test design effort as all of the practical limitations that will be encountered in the field evaluation become known. Obviously, a major limitation that will influence the detailed test objectives, as well as the conclusions of the various test planning tasks, is the amount of funding available for the field evaluation.

The following is a partial list of specific tasks that should be performed during the test planning period:

a. Type of Driving. The types of driving desired for the test should be established, such as driving on urban freeways, open highways, city streets, level roads, and hills. For tests involving fleet vehicles, the number of deliveries made should be considered.

b. Vehicle Characteristics. The types of automobiles and trucks desired for the test program must be considered. For automobile testing, full, compact, and subcompact sizes would probably be desirable. The maximum age of the vehicle to be used for the test should also be determined. The effects of the state of the vehicle maintenance, load, accessories, and types of tires should also be considered.

c. Driver Characteristics. It must be determined insofar as it is possible if certain driver characteristics such as age, sex, and education level will influence test results. The factors that will be considered in selecting drivers for the test must also be established.

d. Human Factors. Before the driver aid devices are selected, consideration must be given to how drivers react to various types of displays and information feedback such as dials, lights, buzzers, and increased pedal pressure.

e. Safety Hazards. A driver aid device that requires constant monitoring may be a safety hazard. Similarly, a bright light could also distract the driver. An evaluation of all possible safety hazards must be made before final selection of the driver aid device.

f. Selection of Test Groups. The specific groups that will participate in the tests must be selected during the test planning phase. Both the general driving public and professional fleet drivers are potential candidates. The individual drivers could be selected based upon a random selection of automobile registrations or driver licenses, employees of some organization, either government or industry, or driver organizations such as the American Automobile Association. Fleet drivers could also be selected from either government or industry. The type of driving of the fleet selected should obviously be representative of fleets using that type of vehicle. Other factors to be considered in selecting the fleet group are the cooperativeness of the management and the personnel, and agreement with the management on how fleet drivers will be motivated.

g. Device and Vehicle Compatibility. It should be determined if candidate driver aid devices have any installation or operational problems associated with any particular vehicles considered for the test program.

h. Driver Aid Device Selection. The selection of the driver aid devices must be based on the test objectives and the factors previously considered, as well as the device performance, driver motivation potential, availability, cost, and installation time.

i. Vehicle Instrumentation. The instrumentation required for each vehicle participating in the test must be determined. The options range from no instrumentation at all with the driver recording the mileage, amount of fuel used, and driving conditions, to recording equipment that would record, as a function of time, the amount of fuel used, speed of the car, acceleration, and manifold vacuum.

j. Driver Training. The options for driver training that must be considered are classroom instruction, self-instruction by means of reading a booklet, driver training in a vehicle, or some combination of these methods.

k. Survey Forms. Questionnaires must be designed that will be completed by the drivers participating in the tests to determine their reaction to the driver training and driver aid devices. Separate questionnaires could be completed by the participants before, during, and after the tests. It should be determined how many questionnaires are necessary.

l. Test Size and Length Determination. By means of appropriate statistical analyses, the required sample size and the length of the test must be estimated, although final determination of these factors may not be possible until some test data are available (see Sections 7.2 and 7.4).

m. Weather. One factor that could limit the length of the test is the weather, since it is well known that weather can have an appreciable effect on fuel economy. For example, it would be undesirable to have the baseline phase of the test in the winter, and the final phase of the test where the driver aid devices are being used in the summer. It must be determined if weather will be a limiting factor, and if so, whether it would be desirable to conduct the test in a region of the country where the climate does not change drastically with the season of the year.

n. Test Sequence. The sequence of the various phases of the test must be established.

o. Data Handling and Processing. The method of data collection and handling and the data processing requirements must be established. Computer requirements must also be established as part of this task.

p. Data Analysis. The techniques to be used in analyzing the data, including statistical methods, must be established.

7.3.2 Pilot Test

The pilot test is a short test conducted with a limited number of participants before the full-scale field test begins. The purpose of the pilot test is to determine any unforeseen testing problems and to attempt to optimize the data that will be obtained from the field test. Specific tasks may include the following:

a. Determine any unanticipated problems associated with the installation of the driver aid devices on the vehicles.

b. Optimize the adjustment of the driver aid devices. For example, for a vacuum device with a warning light, the vacuum level at which the light turns on should be determined. If practical, the acceleration rate that maximizes fuel economy should be determined for each type of vehicle to be used in the field evaluation.

A small test sample will be selected and they will receive instruction and drive the automobiles in the same manner as planned for the full-scale field test. Operational problems involving the driver training, survey forms, and the driver aid devices themselves can be identified. An important objective of this pilot test is to determine a preliminary estimate of the variance of the fuel economy results so that an improved estimate of the length and size of the field test can be made.

7.3.3 Field Evaluation

Detailed specification of the structure of a real field evaluation cannot be determined until after the test planning phase. However, a typical test sequence may be as follows:

a. Select test samples A and B.
b. Monitor the gas mileage of the samples to establish baselines.
c. Instruct the participating drivers in Sample A on how to drive their cars more economically.
d. Monitor the fuel mileage as in Step b to determine the benefit of the instruction.
e. Install a driver aid device and instruct the participating drivers in Sample A on its use.
f. Monitor the gas mileage as in Step b to determine the benefit of the driver aid device.
g. Interview the drivers in Sample A to determine their reaction to the driver aid device.
h. Repeat Steps e, f, and g for Sample B drivers.
i. Repeat Steps c and d for Sample B drivers.
j. Analyze the test data.

7.4 SAMPLE SIZE DETERMINATION CONSIDERATIONS

Suppose that a specific objective of the evaluation is to determine the difference in average gasoline mileage attained under two different conditions, i.e., prior to driver training and after training. Before determining the appropriate number of drivers to monitor, at least approximate answers to three questions must be obtained. First, there must be a specification of the accuracy or precision required of the test result. For example, it would be meaningless to state a mileage improvement of 4 miles per gallon, plus or minus 5 miles per gallon. At the other extreme, it seems clear than an experiment designed to measure mileage improvement to within a hundredth mile per gallon would be needlessly wasteful of time and resources. Not only is this accuracy much greater than that needed to make intelligent decisions regarding the continued development of driver aids, but also a mileage improvement so small as to require this accuracy for its discernment is certainly too small to have an impact on energy consumption.

Second, there must be a judgment made concerning the confidence level at which the test will be performed. The confidence level is a quantitative way of stating the probability with which the test outcome is a result of some causal factor and not just the operation of random chance. In other words, if a confidence level of 0.95 is specified, we are allowing for one chance in twenty that the test outcome was produced by random chance. If 0.99 confidence is specified then the outcome could have been produced by chance with probability only 0.01, or one chance in a hundred. Typically, 0.95 is considered adequate, but the best choice depends upon the use to be made of the test outcomes and the relative costs of the various decisions that depend upon the test outcomes.

Finally, the selection of the test sample size depends upon at least an estimate of the variability exhibited by the test parameters. As previously mentioned this variability, if not known a priori, can be estimated in a pre-evaluation pilot test. A numerical, hypothetical example that illustrates these factors is given in Appendix B.

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APPENDIX A

INTERRELATIONSHIPS INFLUENCING AUTOMOBILE PERFORMANCE AND FUEL ECONOMY[1]

The performance and fuel economy of an automobile are determined by detailed engineering characteristics of the specific vehicle, vehicle operating requirements, and demands of the driver. The following provides a brief explanation of some of the basic interrelationships of design and operating parameters.

The basic physical law governing the motion of an automobile is Newton's second law of motion. In order to place an automobile in motion, a force must be exerted through the vehicle driving wheels. The amount of the force depends on the weight of the car and the rate of vehicle acceleration, as well as the magnitude of forces that retard motion such as rolling resistance and aerodynamic drag.

The motive force is applied to the vehicle driving wheels by a combination of the operation of the vehicle engine, transmission, and drive axle. The function of the transmission and drive axle is to deliver the turning effort of the engine to the driving wheels at a speed different from that of the engine. This difference in speed also implies a multiplication of the turning effort of the engine, depending on the value of the overall gear ratio.

The turning effort of the engine is termed torque and arises as a result of ignition and subsequent expansion of the products of combustion of a hydrocarbon fuel and air mixture within the cylinders of an internal combustion engine. Detailed design characteristics of specific internal combustion

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[1] The exposition of performance and fuel economy relationships in this Appendix is largely based on a similar treatment developed by the Southwest Research Institute in Reference A-1. Supplementary material from References A-2 through A-5 have been incorporated for further clarification and emphasis.

engines determine the amount of torque produced by that engine. Basically, however, it is the quantity of fuel and air ingested by the engine during each revolution that determines the amount of torque produced. Typically, small-displacement engines produce less torque than larger-displacement engines, all other factors being equal.

Traffic conditions require that a vehicle be operated at varied speeds and accelerations, all of which require varied torques. Ignoring the transmission momentarily, the torque needed to sustain the desired operating condition is obtained by varying the amount of fuel-air mixture processed by the engine. For a vehicle with a carbureted engine this variation is, in effect, accomplished by the modulation of the accelerator pedal. Depressing the accelerator allows more mixture to enter the engine, thus producing more torque. Of course, there is a limit to the amount of torque that any engine with fixed design characteristics can produce. This maximum torque at any given engine speed is produced at wide open throttle (WOT). The generalized torque characteristic of an internal combustion engine is shown in Figure A-1.

The transmission is used to multiply the torque output of the engine so that the vehicle can be subjected to motive forces higher than could be

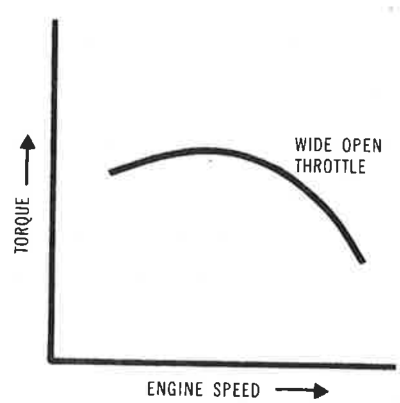

Figure A-1. Generalized Engine Torque Characteristic (Ref. A-1) developed by the direct connection of the engine to the drive axle. Transmission gear ratios greater than 1:1 allow the torque necessary to move the vehicle to be delivered at smaller throttle (accelerator) settings. In order to meet any given vehicle torque requirement, many gear ratios and various combinations of engine displacement and throttle openings can be used.

As the motive force acts on the vehicle, the vehicle begins to move. The force, of course, then acts on the vehicle over the distance through which the vehicle moves. This quantity (force × distance) is termed work, and the rate at which the work is done is termed power. In engineering terms, the power output of an engine is specified as power = torque × revolutions per minute × constant. The constant is selected to get the units of power into a comparative unit of measure, such as horsepower. In essence, power is the price one has to pay when demanding a given force at a given speed. It is the power requirement of the desired motion of an automobile, relative to the overall efficiency of the translation of the energy of combustion into meeting this power demand, that determines automobile economy.

The conventional naturally aspirated carbureted engine demonstrates a performance (torque versus revolutions per minute) map under fully warmed up conditions similar to Figure A-2. The contours are lines of constant fuel consumption for each unit of horsepower developed (brake specific fuel consumption). This characteristic map results from two primary effects. The first is the increase in brake specific fuel consumption (BSFC) with decreasing torque output at a constant engine speed, which is due to the higher percentage of friction power at low brake power outputs. Second, brake specific fuel consumption increases with increasing speed (at constant torque) because of increased engine friction. Consequently, the highest fuel use efficiency for the engine occurs at low engine speeds and high torque outputs.

The engine performance map is an extremely significant constituent of the overall vehicle fuel economy formulation. This map is the representation of the units of fuel consumed in meeting the power demanded by the motion

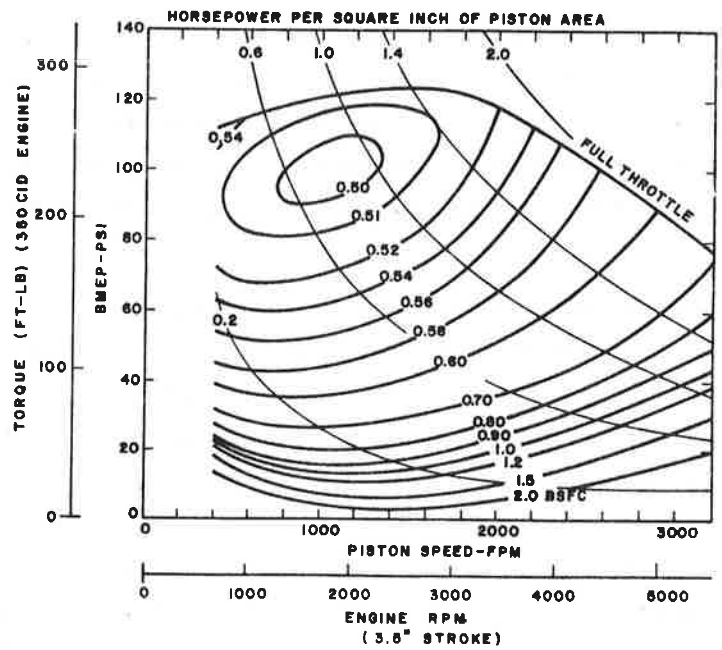

Figure A-2. Performance Map of a Carbureted Spark Ignition Engine (Ref. A-1)

of the vehicle. The values of the brake specific fuel consumption, as well as the shape of the characteristic fuel-consumption curves, are extremely significant in determining accurate estimates of economy.

Unfortunately, conventional applications of engines to vehicles result in a compromise of where the engine operates in the map under road-cruising conditions relative to the maximum performance capability of the vehicle. This is illustrated in Figure A-3. The road load is met at points of high brake specific fuel consumption, and the difference between the torque capability at full throttle and the road-load torque value determines the performance (acceleration) capability of the vehicle. If design characteristics of a vehicle were adjusted such that the road-load power requirements could be met by operating near the point of minimum brake specific fuel consumption, a marked improvement in fuel economy could then be gained. However, such a

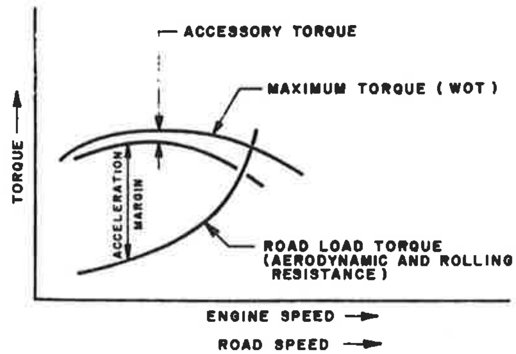

Figure A-3. Generalized Engine and Vehicle Torque Characteristics (Ref. A-1)

move with conventional technology (such as a very small engine) would also result in substantial reduction in the acceleration and passing capabilities of a full-size automobile.

The foregoing discussion stressed the difference between the full power capability of a vehicle and the power necessary to maintain level-road motion (no acceleration). For a full-size automobile, typical road-load power requirements are given in Figure A-4.

This power requirement is determined by a large number of factors, including vehicle weight, accessories used, drive train losses, tire design and construction, road surface conditions, air temperature and density, and vehicle size and shape (aerodynamic drag). The vehicle design must accommodate a range of power requirements that result from operation throughout the United States. For example, at an altitude of 4000 feet, the road load at 70 miles per hour is reduced by 3.8 horsepower, or about 10 percent, as a result of the decreased air density. Operating a vehicle in a 0°F ambient instead of a 100°F ambient increases the road load by about 12 percent at 70 miles per hour. Fuel economy, then, can be seen to be influenced by ambient conditions as well as the vehicle operating requirements.

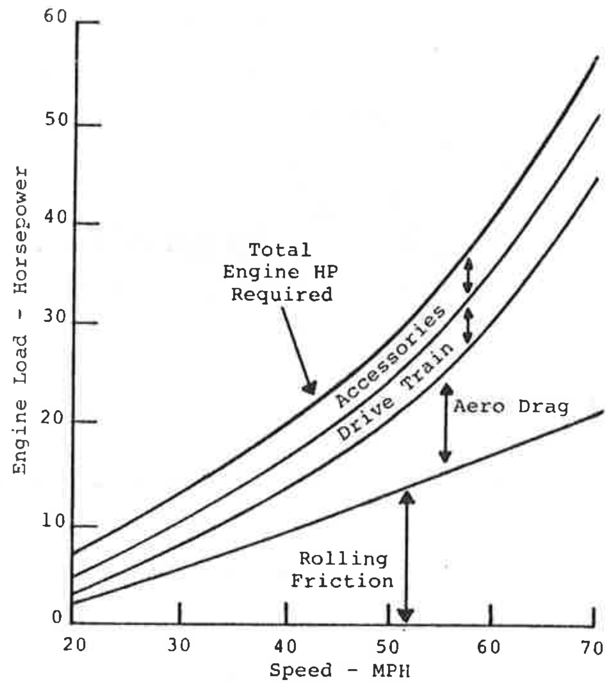

Figure A-4. Effect of Speed on Power Requirements (Ref. A-2)

Figure A-5 illustrates the fuel consumption characteristics of a typical engine as a function of power, revolutions per minute (rpm), and rear axle ratio. As can be noted, there is a very broad range of power over which the engine will produce near-minimum fuel consumption. Ideally, for minimum fuel consumption, the transmission should fix the engine speed so the operating point falls on the envelope of the rpm curves, regardless of the power demand. Typical road-load operating curves for an automatic transmission with two different axle ratios (3.42 and 2.53) are shown. Some gains in economy are obtained by lowering the numerical axle ratio at a sacrifice, however, in acceleration capability.

The fuel economy measured under level-road conditions is one method for comparing vehicle designs. Figure A-6 illustrates typical road-load fuel economy for three vehicle classes. However, the vehicle must be

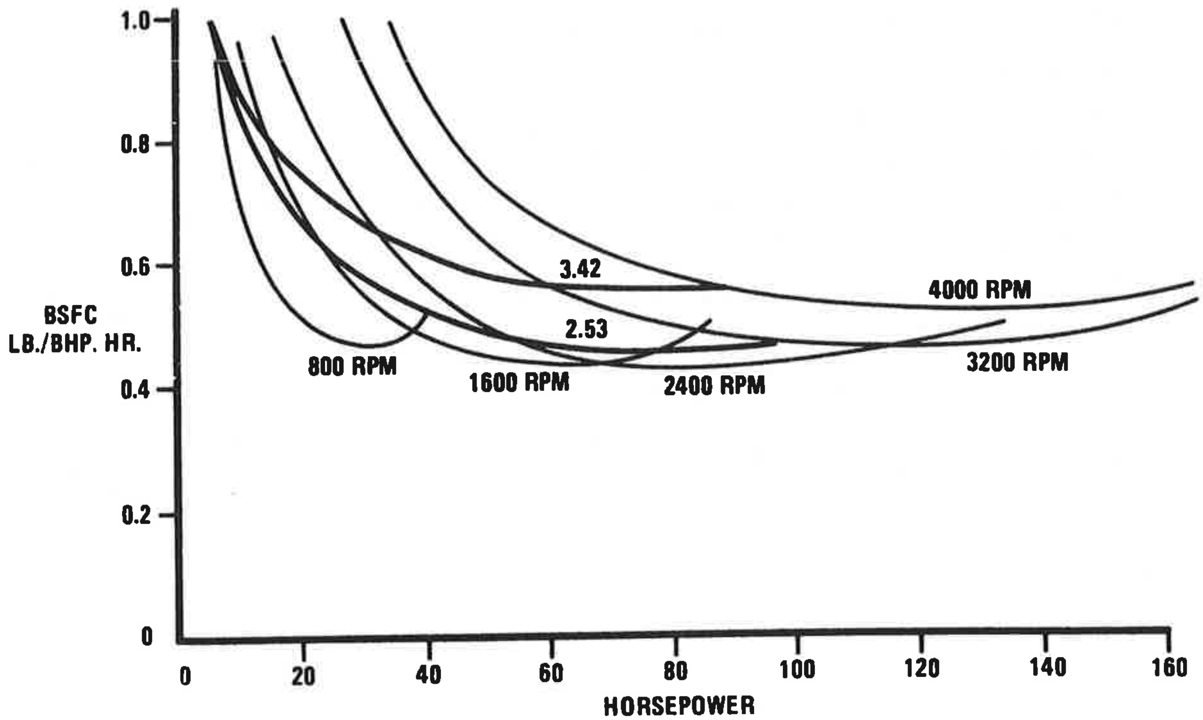

Figure A-5. Specific Fuel Consumption Versus Power (Ref. A-3)

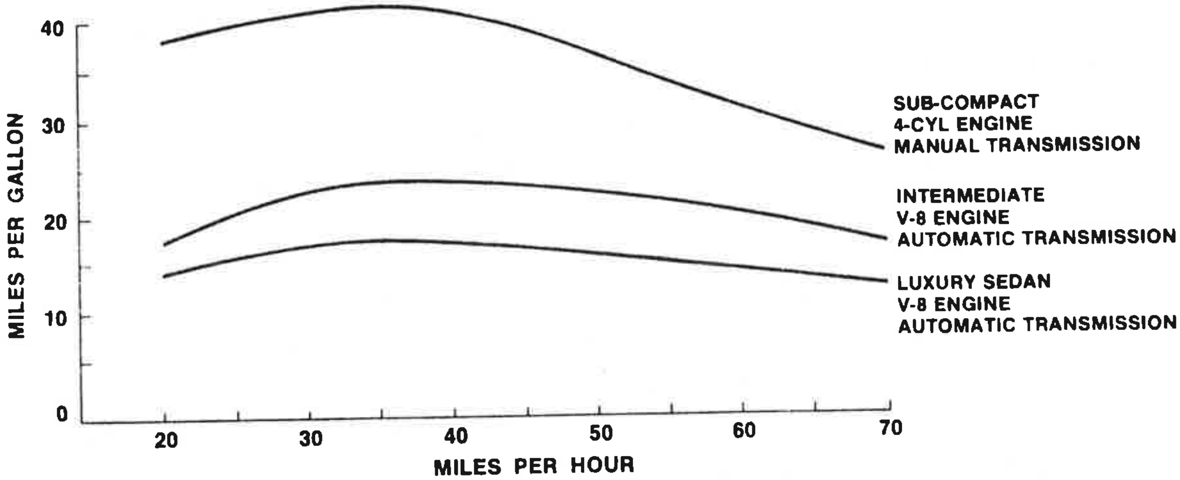

Figure A-6. Road-Load Fuel Economy — Steady-Speed Operation on a Level Road (Ref. A-4) capable of meeting varied road conditions, such as grades. "Level" sections of interstate highways are not always level. Often highways include grades, and a 3-foot rise in 100 feet of road is not uncommon. The conventional American automobile can negotiate such grades without requiring downshift to a lower gear. The significance of grades on vehicle-power requirements is illustrated by Table A-1.

TABLE A-1. THREE-PERCENT GRADE POWER REQUIREMENTS FOR A 4300-POUND VEHICLE (Ref. A-1)

Speed (mph)	Additional Grade Horsepower	Increase Over Level Road (%)
20	6.88	137.0
30	10.32	143.0
40	13.75	105.0
50	17.19	90.0
60	20.63	74.0
70	24.07	63.0

Negotiating a grade of only 3 percent more than doubles the road-load power requirements at speeds up to 40 miles per hour and requires a substantial increase even at 70 miles per hour.

A vehicle cannot be designed to maximize economy under specfic level road conditions but must be designed to accommodate a wide range of driving conditions encountered in the United States. In addition to steady-state driving conditions, transient operation of vehicles is also extremely important. Stop-and-go traffic conditions such as accelerations, braking, and idling, constitute typical driving conditions experienced by the driving public. Trip patterns have been studied extensively by the U.S. Department of Transportation, the Environmental Protection Agency, auto manufacturers, the Society of Automotive Engineers, and others. These studies have found that trip length has a large effect on average trip speed, as shown in Figure A-7. In fact, there is a direct correlation between frequency of stops and the average

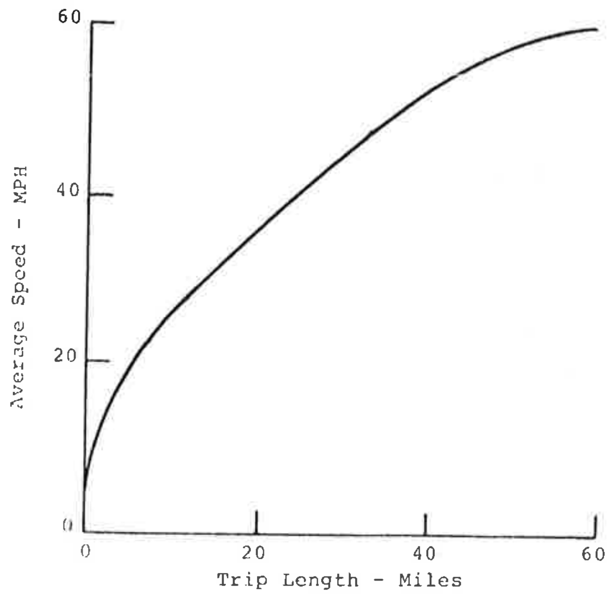

Figure A-7. Average Trip Speed Versus Trip Distance (Ref. A-2)

speed of the trip, as illustrated in Figure A-8. The line in this figure comes from measurements taken in actual traffic. The figure also shows the average speed and stopping frequencies for test procedures developed by the Environmental Protection Agency, the Society of Automotive Engineers, and a major auto manufacturer. While the average speeds of these procedures vary, they all correlate well with the traffic measurements for the conditions (urban or highway) that they were designed to simulate.

The fuel economy effects of these varying trip characteristics appear in Figure A-9, for a standard-size car and a compact. Economy under cruise conditions for the same cars is also shown for comparison.

Under acceleration, weight is the most important parameter influencing fuel consumption. Figure A-10 clearly establishes the magnitude of this power demand. The LA-4 cycle shown corresponds to the EPA Urban Dynamometer Driving Schedule used for vehicle emission certification tests. Under the maximum acceleration requirements of the LA-4 cycle, the power

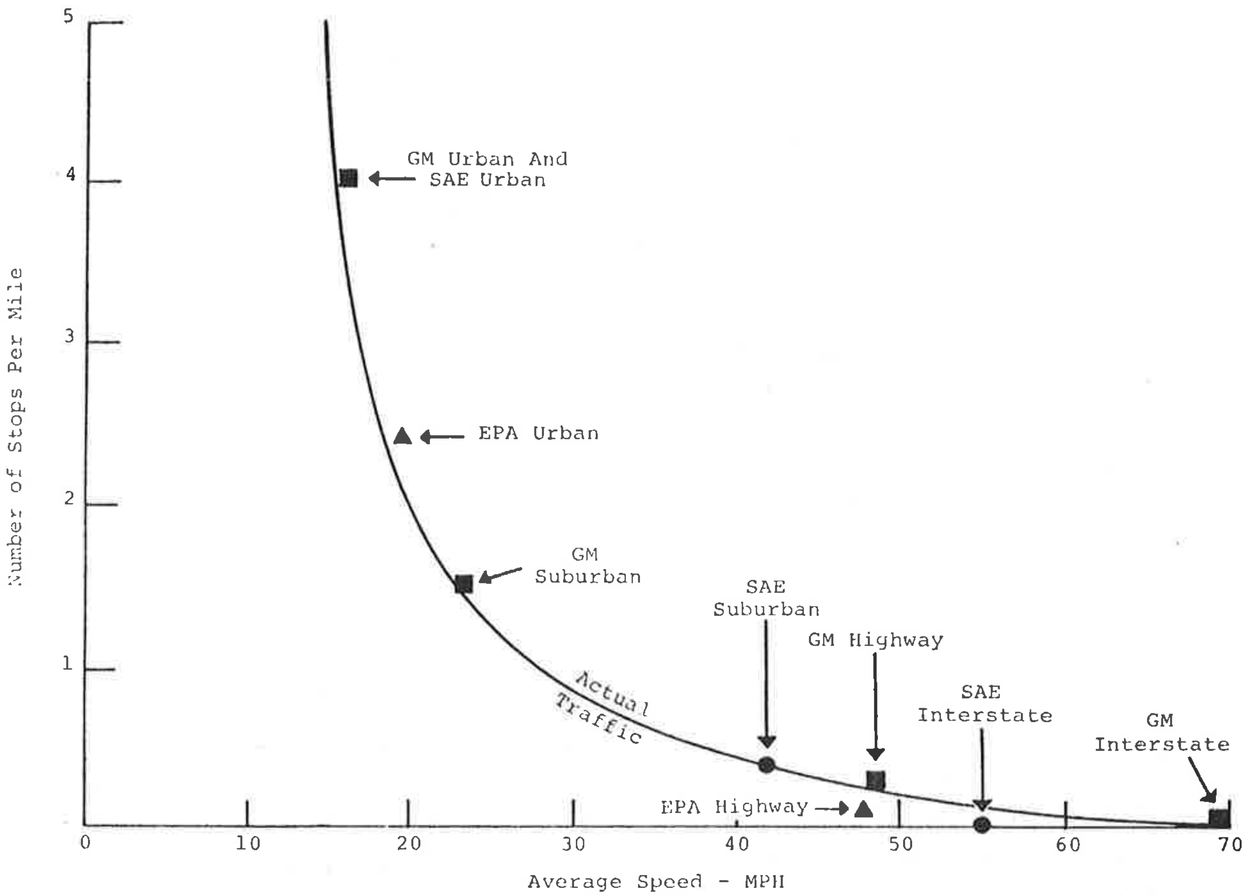

Figure A-8. Stopping Frequency Versus Average Speed for Cyclic Trips (Ref. A-2)

required to accelerate the 4300-pound vehicle is over six times that required to maintain steady motion at 30 miles per hour. Also shown for reference are the power requirements of accelerating the vehicle at other performance levels. It should be noted that the maximum performance of a full-size reference vehicle lies somewhere between 5 and 6 seconds to 30 miles per hour. The performance capability of a given weight vehicle then can be seen to influence significantly the power required and, consequently, the fuel consumption. For further comparison, Figure A-11 illustrates the power requirements of

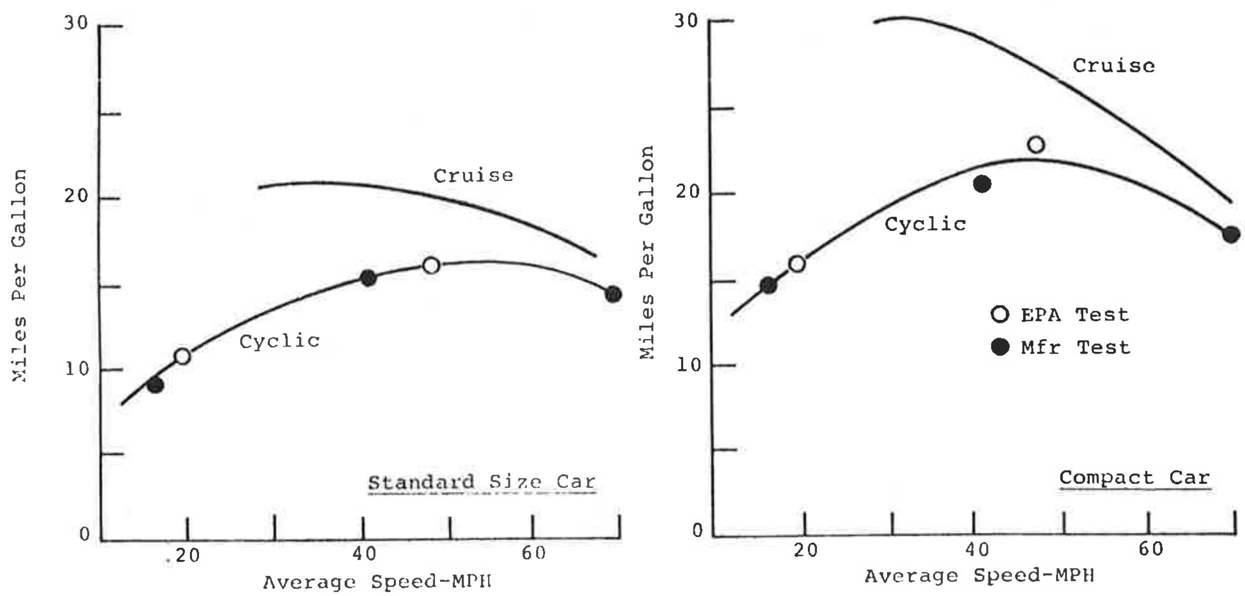

Figure A-9. Influence of Driving Patterns on Fuel Economy (Ref. A-2)

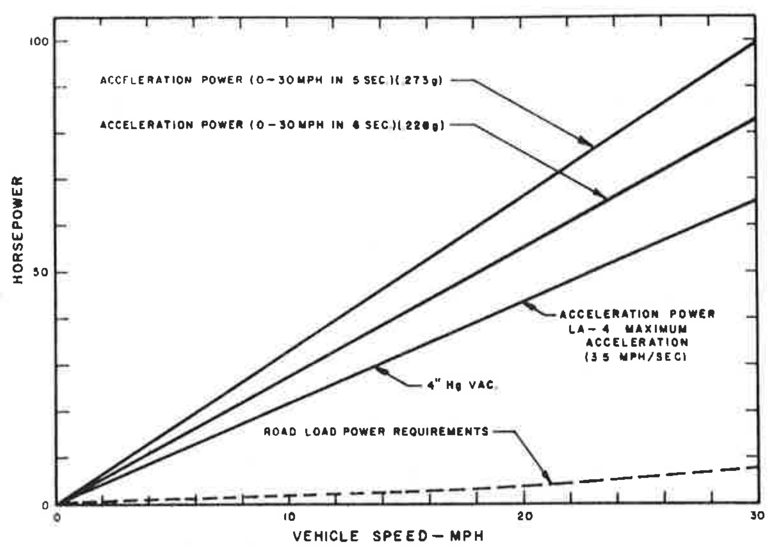

Figure A-10. Motive Power Requirements for a 4300-Pound Vehicle (Ref. A-1)

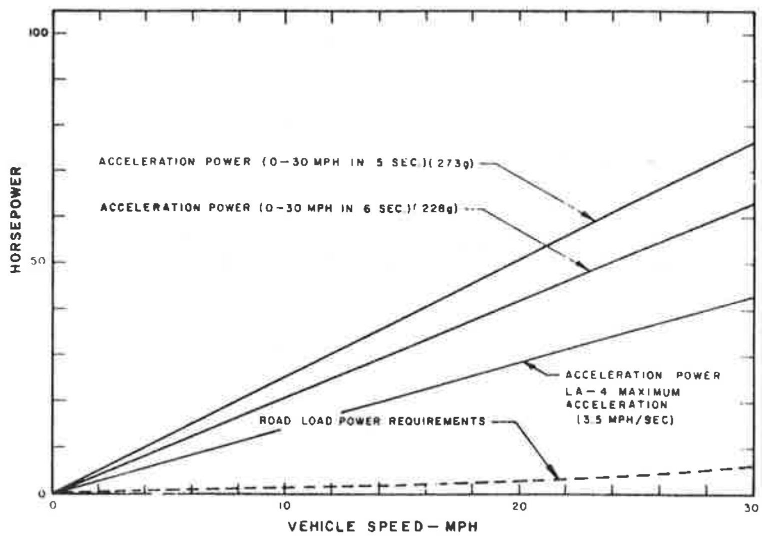

Figure A-11. Motive Power Requirements for a 3300-Pound Vehicle (Ref. A-1)

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a 3300-pound vehicle under the same acceleration loads. The requirements here are 3300/4300 = 76.7 percent of the loads for the 4300-pound vehicle. The influence of vehicle weight can be marked; however, the significance over a driving cycle will depend on the amount of time spent in acceleration modes and the amount of acceleration demand.

The weight of the vehicle is the primary factor that determines the installed power requirements of the vehicle when a given level of performance is specified. For example, in determining the power necessary to accelerate a 4300-pound vehicle to 30 miles per hour in 5 seconds, less than a 10-percent error would be encountered in totally ignoring the road load. Unless the performance level or weight of a full-size vehicle is significantly reduced, the maximum power output of the engine must remain at previously used levels. Figure A-12 illustrates the sales weighted fuel economy of 1975 model vehicles by weight class as a function of city driving (the LA-4 cycle) and the Environmental Protection Agency highway driving cycle.

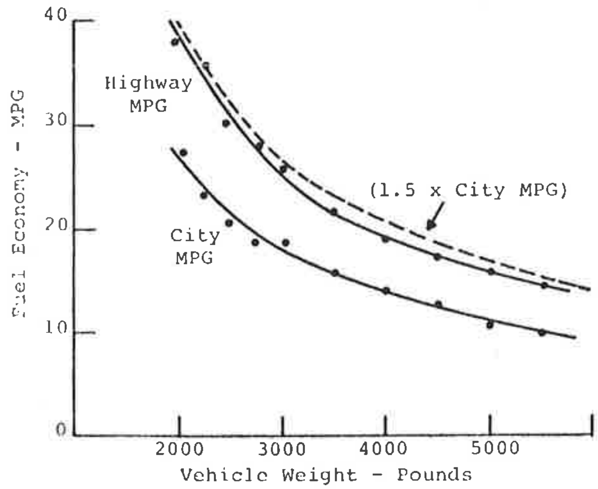

Figure A-12. Fuel Economy of 1975 Models by Test Weight Class (Sales Weighted)(Ref. A-2)

The influence on vehicle operating fuel economy because of starting and operating a vehicle "cold" as compared to "warm" is significant. The loss in fuel economy is attributable to varied sources including carburetion enrichment to maintain the air-fuel ratio of the engine cylinders, viscous losses in cold engines, transmissions, and axles, and higher heat losses in the engine caused by rejection of heat to "cold" coolant. Since these effects are thermal, ambient temperature would be expected to influence the amount of fuel economy degradation, which Figure A-13 illustrates. These curves were developed from sequential repetition of a driving cycle. Obviously, the driver who makes short trips in cold climates will suffer a significant reduction in his fuel economy from that obtainable from a fully warmed up engine.

Table A-2 illustrates that over half of the trips taken in the United States are under 5 miles. Although the total miles driven for these short trips are not a major portion of the total travel, improvements in the fuel consumption during warm-up will also decrease the overall energy demand.

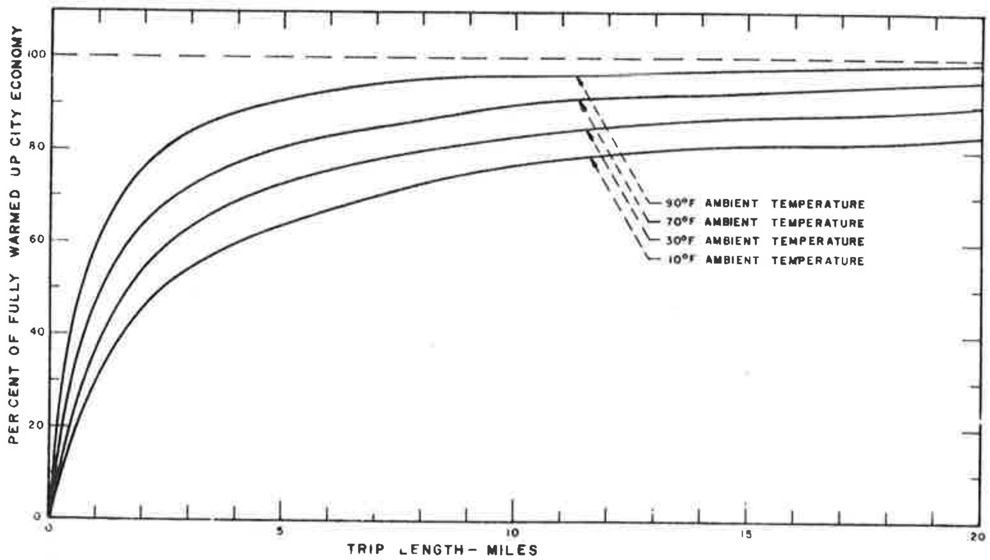

Figure A-13. Warm-Up Economy (Ref. A-5)

The Environmental Protection Agency has correlated data on fuel economy versus speed, trip length, and trip distribution, and found that a significant amount of travel in the United States involves less-than-optimum fuel economy. The mileage and fuel consumption effects are summarized in Figure A-14, which shows that trips of 5 miles or less make up approximately 15 percent of all auto trip miles, but consume more than 30 percent of all auto fuel.

TABLE A-2. AUTO TRIP STATISTICS (Ref. A-1)

Urban Mileage		
Trip Length, One-Way Miles	Trips (%)	Vehicle Miles (%)
Under 5	54.1	11.1
5-9	19.6	13.8
10-15	13.8	18.7
16-20	4.3	9.1
21-30	4.0	11.8
31-40	1.6	6.6
41-50	0.8	4.3
51-99	1.0	7.6
100 and over	0.8	17.0
Total	100.0	100.0
Total Mileage (%)		
Urban	55.5	
Highway	44.5	

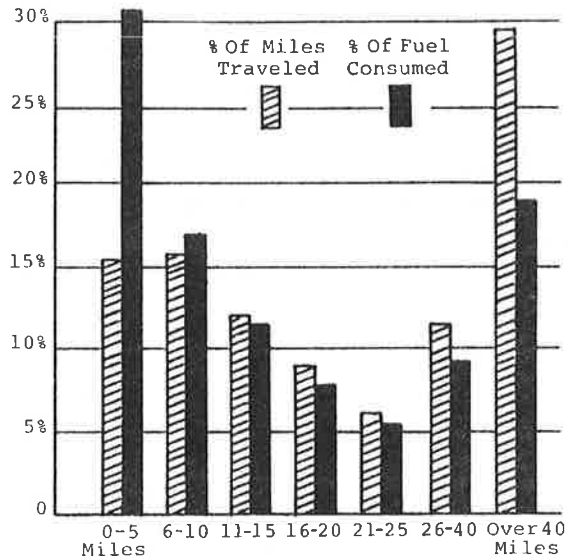

Figure A-14. Distributions of Trip Mileage and Fuel Consumption (Ref. A-2)

APPENDIX B

EXAMPLE OF SAMPLE SIZE DETERMINATION CONSIDERATIONS

It is considered that implementation of a particular driver aid program will result in a mileage increase of 3 to 4 miles per gallon. Or alternatively, it may be considered that unless the average improvement is not at least 2 miles per gallon, it is not feasible to continue with that particular program. At any rate, an experiment precision of about 1 mile per gallon is required. Also, suppose after considerable discussion of the risks associated with experimental variability and the corresponding costs of incorrect decisions, it is decided that a risk of random occurrence equal to one chance in twenty is considered appropriate. The test will therefore be designed for a confidence level of 0.95. As previously stated, the width of a γ-level confidence interval for the difference in mean of two Gaussian populations is

$$W = 2k_\gamma \sigma \sqrt{\frac{1}{M} + \frac{1}{N}} \tag{B-1}$$

If, for simplicity, the two samples are taken to be of equal size, M = N and Equation (B-1) becomes

$$W = 2\sqrt{2}\, k_\gamma \sigma / \sqrt{N} \tag{B-2}$$

The precision requirement can be implemented by requiring that the width of the confidence interval be no greater than some number, e.g., W_0, which for the present discussion will be taken as $W_0 = 1$ mpg. Equation (B-2) can then be solved for an inequality constraint on the sample size N

$$\text{For} \quad W \leq W_0 , \quad W \geq 2\sqrt{2}\, k_\gamma \sigma / W_0$$

or

$$N \geq 8 \left(k_\gamma \sigma / W_0\right)^2 \qquad \text{(B-3)}$$

The parameter remaining to be determined before the inequality can be solved for the minimum sample size is the population variance σ. As an attempt to estimate σ, suppose that the average mileage performance of a group of drivers was monitored in a pilot test sample. In this case, 15 drivers were monitored for a period of time sufficiently long that random fluctuations in time were averaged out. The data, which was actually obtained in a study conducted by the Douglas Aircraft Company (Ref. B-1) is given in Table B-1.

TABLE B-1. PILOT TEST MILEAGE RESULTS — PREINSTRUCTION PHASE

Driver	Mileage (mpg)	Driver	Mileage (mpg)	Driver	Mileage (mpg)
1	11.0	6	13.6	11	11.6
2	11.4	7	13.4	12	12.7
3	9.5	8	10.5	13	10.2
4	12.7	9	12.0	14	14.6
5	14.3	10	11.1	15	11.1

The sample mean and variance associated with these data are

$$\bar{x} = 11.98 \text{ mpg} \qquad \text{(B-4a)}$$

$$s_x^2 = 2.32 \text{ mpg}^2 \qquad \text{(B-4b)}$$

For a Gaussian population, the quantity

$$\chi_M^2 = \frac{\sum^M (x_i - \bar{x})^2}{\sigma^2} = \frac{(M-1)s^2}{\sigma^2} \tag{B-5}$$

is distributed as χ^2 with M-1 degrees of freedom. Thus, an upper bound for σ can be established from a table of χ^2 variates, e.g., at the 0.95 level, as

$$0.95 = \Pr\left\{6.57 \le x_{14}^2 \le \infty\right\}$$

or

$$0.95 = \Pr\left\{6.57 \le \frac{14 \times 2.32}{\sigma^2} \le \infty\right\}$$

$$= \Pr\left\{0 \le \sigma^2 \le 4.94\right\}$$

or

$$0.95 = \Pr\left\{0 \le \sigma \le 2.22 \text{ mpg}\right\} \tag{B-6}$$

Thus, with 0.95 confidence, σ is no greater than 2.22 mpg, and inequality (B-3) can be evaluated with roughly the same confidence. Taking $W_0 = 1$ mpg and $\gamma = 0.95 \rightarrow k_\gamma = 1.96$, inequality (B-3) becomes

$$N \ge 152 \tag{B-7}$$

Roughly stated, there is confidence in the neighborhood of 0.95 that a test with a sample size of at least 152 will yield average mileage estimates with a precision of 1 mile per gallon.

As an example of a comparison technique, one may consider the performance of the same 15 drivers enumerated in Table B-1 after a period of driver instruction carried out at Douglas Aircraft. Though the sample size has been shown to be inadequate for a 1-mpg precision, it is instructive to carry through the analysis to demonstrate how mileage improvement conclusions can be obtained. Table B-2 contains both the pre- and post-instruction mileage data for all 15 drivers together with the sample means and variances for the two sets of measurements.

TABLE B-2. AVERAGE MILEAGE DATA BEFORE AND AFTER DRIVER INSTRUCTION PROGRAM

Driver	Pre-Instruction (mpg)	Post-Instruction (mpg)
1	11.0	16.5
2	11.4	14.2
3	9.5	15.5
4	12.7	14.7
5	14.3	15.0
6	13.6	15.2
7	13.4	14.9
8	10.5	14.7
9	12.0	15.6
10	11.1	15.8
11	11.6	15.6
12	12.7	15.2
13	10.2	14.3
14	14.6	15.2
15	11.1	15.7
sample mean	$\bar{x}$ = 11.98 mpg	$\bar{y}$ = 15.21 mpg
sample variance	s_x^2 = 2.316 mpg	s_y^2 = .387 mpg

It can be shown, again for Gaussian populations, that the statistic

$$t_{2(n-1)} = \sqrt{n(n-1)}\ \frac{\bar{y} - \bar{x} - (\mu_y - \mu_x)}{\sqrt{\Sigma(x_i - \bar{x})^2 + \Sigma(y_i - \bar{y})^2}}$$

or

$$t_{2(n-1)} = \frac{\sqrt{n}}{\sqrt{s_x^2 + s_y^2}} \left[\bar{y} - \bar{x} - (\mu_y - \mu_x)\right] \qquad \text{(B-8)}$$

has the Student-t distribution with 2(n-1) degrees of freedom, where μ_x and μ_y are the true average mileages before and after the instruction. From tables of the t distribution, with 0.95 confidence,

$$0.95 = \Pr\left\{-\infty < t_{28} < 1.701\right\} \qquad \text{(B-9)}$$

Substitution in Equation (B-9) for t_{28} from Equation (B-8) and using the data of Table B-2 yields

$$0.95 = \Pr\left\{2.508 \leq \mu_y - \mu_x < \infty\right\} \qquad \text{(B-10)}$$

The conclusion from the pilot survey data can now be stated: with confidence 0.95, the improvement in average mileage based on a before-and-after sample of 15 drivers is at least 2.5 miles per gallon.

APPENDIX C

REPORT OF INVENTIONS

This report provides a summary and overview of existing informational devices designed to assist the automobile driver to save gasoline and therein lies its value. A diligent review of the work performed under this contract has revealed no innovation, discovery, improvement, or invention.

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