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HIGHWAY VEHICLE RETROFIT EVALUATION
PHASE II REPORT
TESTING AND FINAL EVALUATION RESULTS

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16. Abstract

This report presents the results of engine dynamometer and vehicle chassis dynamometer tests conducted with selected automotive retrofit devices in the classes of ultrasonic carburetors, high-velocity intake manifolds, tuned exhaust systems, and high energy ignition systems. The test results obtained by the two test methods are compared and discussed.

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PREFACE

This report, prepared by The Aerospace Corporation for the U.S. Department of Transportation (DOT), Transportation Systems Center (TSC), as part of their Automotive Energy Efficiency Program, presents the results of a test program conducted to evaluate the fuel economy improvement potential of selected automotive retrofit devices.

This test program represented a second phase of an overall evaluation of highway vehicle retrofit concepts. In the first phase of the program, over twenty representative classes of retrofit devices/concepts/techniques, including over 130 specific items, were analyzed and evaluated, based on available comparative test data and the general operational principles of specific devices.[1] The spectrum of devices examined included: carburetors; acoustic and mechanical atomizers; lean-bleed devices; vapor injectors; fuel modifications; inlet manifolds; ignition systems; drive train components; drag reduction techniques; driver aids; cooling fans; valve timing modifications; tuneups; compression ratio increases; exhaust-related systems; and engine oils, oil additives, and filters.

It was concluded in Phase I that there were insufficient test data to fully evaluate several potentially promising retrofit device classes, including: ultrasonic carburetion, high-velocity intake manifolds, tuned exhaust systems, and high-energy ignition systems. Therefore, selected devices within these classes were tested for this purpose with the results as presented herein.

Appreciation is acknowledged for the guidance and assistance provided by Mr. Michael D. Koplow of the Department of Transportation, Transportation Systems Center, who served as DOT/TSC Technical Monitor for this study.

The following technical personnel of The Aerospace Corporation made valuable contributions to the study: M. G. Hinton, L. Forrest, and W. B. Lee.

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[1] "Highway Vehicle Retrofit Evaluation, Phase I, Analysis and Preliminary Evaluation Results," Report No. DOT-TSC-OST-75-48, November 1975.

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SUMMARY

Several automotive retrofit devices were tested to evaluate their fuel economy improvement potential in Phase II of the Highway Vehicle Retrofit Evaluation study program. Those devices which were selected for testing in Phase II of the program were those which had been analyzed and evaluated in Phase I of the study[1] and which (a) were considered to have the potential for fuel economy improvement of 5 percent or more, (b) required additional confirmatory testing to adequately establish their fuel economy improvement potential, and (c) were available and within the scope of Phase II efforts insofar as tests with and without the device were considered sufficient to establish their relative merit. These devices included: the Ultrasonic Fuel System carburetor, high-velocity intake manifolds, tuned exhaust systems, a multiple spark capacitive discharge ignition system, and the combination of intake manifold plus tuned exhaust system.

All device classes except the Ultrasonic Fuel System were evaluated in both engine dynamometer tests and chassis dynamometer tests. The Ultrasonic Fuel System was tested only on the chassis dynamometer.

The engine dynamometer tests were made for screening and characterization purposes, and were conducted in the Automotive Engineering Laboratory of the University of Michigan, Ann Arbor, Michigan. They consisted of steady-state dynamometer tests of a 1973, 350 CID Chevrolet engine at road-load cruise conditions of 25, 35, 45, 55, and 65 mph, and wide-open throttle (WOT) conditions at 35 and 55 mph. The brake specific fuel consumption (BSFC) was measured at each condition. A baseline condition, with the engine in stock condition in all respects, was run before and after each retrofit device test.

The chassis dynamometer tests were conducted by Olson Laboratories, Livonia, Michigan. The goal of these tests was to evaluate the

[1] "Highway Vehicle Retrofit Evaluation, Phase I, Analysis and Preliminary Evaluation Results," Report No. DOT-TSC-OST-75-48, November 1975.

effectiveness of these devices under conditions which would be likely to exist if they were retrofitted to in-use vehicles. This meant that stock tune conditions of dwell angle, spark timing, and carburetor adjustment should be maintained. The rationale for this approach was that the great majority of car owners involved would not be hot-rod or performance enthusiasts, and would not give special installation instructions. The mechanics involved (both for the retrofit installation and for subsequent tuneups) would thus tune to the engine manufacturer's specifications.

It is important to note that these stock conditions are not necessarily optimum for a particular retrofit device in terms of performance, fuel economy, or driveability. Changing the basic engine tune conditions would represent tampering with the emission control system, however, and would be expected to cause a significant increase in emissions. Also, one could possibly obtain more benefit from the retrofit devices by using an engineering test vehicle which was in ideal maintenance condition throughout the powertrain. This would not represent typical in-use conditions, however. All of these factors must be taken into account when comparing the test data of this report to specific manufacturers' claims.

The significant results of all tests are summarized below. The findings are grouped according to test type.

1.1 ENGINE DYNAMOMETER TEST RESULTS

1.1.1 Two-Venturi Intake Manifold

The Edelbrock Streetmaster intake manifold was tested in the 2-V carburetor configuration. Fourteen to fifteen percent improvements in fuel consumption were observed in the 25 to 35 mph steady-state speed range, with essentially no change at other speed conditions up to 65 mph. Wide-open throttle tests at 35 and 55 mph show a reversed trend, with improvements of 3 and 5 percent, respectively.

1.1.2 Four-Venturi Intake Manifolds

Both the Edelbrock Streetmaster and the Offenhauser Dual Port intake manifolds were tested in the 4-V carburetor configuration (the Offenhauser manifold was only available as a 4-V unit). The Edelbrock unit had a small improvement in fuel consumption (approximately 6 percent) at 25 mph conditions and small losses (up to 2 percent) over the rest of the speed range (up to 65 mph). The Offenhauser unit had a loss (approximately 6 percent) at 25 mph and slight gains (2 to 5 percent) over the 35 to 55 mph speed range, with no change at 65 mph. The general trends of these two units were not considered to imply significant improvements over the stock 4-V intake manifold configuration.

1.1.3 Tuned Exhaust Systems

Both Hooker and Hedman tuned exhaust systems were tested and both exhibited very similar trends. Poorer fuel consumption was observed at steady-state speeds below 50 mph (e.g., 6 to 8 percent increase in fuel consumption at 35 mph, 2 to 5 percent increase at 25 mph, 2 to 3 percent increase at 45 mph). Small improvements (2 to 3 percent) were observed at 55 to 65 mph conditions. At WOT conditions, 4 to 5 percent improvements occurred at 55 mph, with very little change (plus 2 to minus 1 percent change in fuel consumption) at 35 mph conditions.

1.1.4 Combination of Two-Venturi Intake Manifold plus Tuned Exhaust System

The combination of the Hooker tuned exhaust system and the Edelbrock Streetmaster intake manifold was tested in the 2-V carburetor configuration. The combined systems displayed a measurable and consistently beneficial fuel consumption trend across the speed range tested: fuel consumption reductions of 5, 4, 2, 4, and 7 percent at 25, 35, 45, 55, and 65 mph, respectively. At 55 mph WOT conditions, the fuel consumption reduction was 4 percent.

1.1.5 Capacitive Multiple Spark Discharge Ignition System (MSD-2)

The capacitive multiple spark discharge ignition system tested was the Autotronics MSD-2 device. This device was tested with the stock 2-V engine test configuration. The observed fuel consumption changes were minimal, with very slight improvements (in the order of 1 percent) noted across the 25 to 65 mph speed range.

1.1.6 Air-Fuel Ratio and Spark Plug Gap Effects

Additional tests were made at 35 and 55 mph steady-state road-load conditions to indicate possible effects at lean air-fuel ratios and advanced timing. Three ignition systems [stock, MSD-2, and a multiple restrike ignition system (MRI)] and three spark plug gap settings (0.035, 0.060, and 0.080) were employed at both stock timing conditions and minimum advance for best torque (MBT) timing. In general, there was no significant difference in BSFC among the three ignition systems; that is, the effects observed were plug-gap and timing-related only.

At the 35 mph test condition with stock timing, for all practical purposes the effect of plug gap was also small. At the leaner air-fuel ratios (more than 17), the 0.080 plug gap had some benefit. With MBT timing, increasing the plug gap from 0.035 to 0.060-0.080 resulted in significant decreases (approximately 5 percent) in BSFC. At very lean mixtures, in the 17 to 20 range, the high-energy ignition systems (MSD and MRI) were improved over the stock ignition system with 0.060 plug gap. On an overall basis, advancing the timing to MBT and increasing plug gap to 0.060 resulted in a 15 percent improvement in BSFC. Although the stock ignition system performed adequately at these steady-state test conditions, the higher energy ignition system probably would be required to assure acceptable idling and acceleration operation.

Similar test results were obtained at the 55 mph test condition. There were two major differences. One was a shift in the air-fuel ratios for minimum BSFC from 16-16.5 at 35 mph to 17-18 at 55 mph. The second was that at stock timing, increasing the plug gap from 0.035 to 0.060 or 0.080 had a noticeable beneficial effect, whereas the impact of such changes were minimal at the 35 mph condition.

These trends are indicative of what has been achieved in some 1975 and 1976 model year cars which have returned to near-MBT timing with the use of catalysts for HC and CO control, and which have incorporated high-energy ignition systems. On a retrofit basis, however, this would require substantial distributor modifications, as well as the addition of a new ignition system.

1.2 CHASSIS DYNAMOMETER TEST RESULTS

1.2.1 Test Plan

The devices tested were:

a. Edelbrock High Performance Intake Manifold (Edelbrock Equipment Company, El Segundo, Calif.)

b. Hooker Tuned Exhaust Headers (Hooker Industries, Ontario, Calif.)

c. Edelbrock Intake Manifold plus Hooker Tuned Exhaust Headers

d. MSD-2 Multiple Spark Discharge Ignition System (Autotronic Controls Corporation, El Paso, Texas)

The retrofit devices were installed in a 1973 Chevrolet Impala, equipped with a stock 350 CID engine, 2-barrel carburetor, and automatic transmission.

The test series for each configuration (plus the baseline, stock configuration) consisted of two replicate tests in the following sequence: 1975 Federal Test Procedure (FTP), EPA Highway Fuel Economy Test (HWFET), and steady-state fuel economy and emissions tests at 35 and 55 mph.

1.2.2 Emissions and Fuel Economy Test Results

Abstracted results for fuel economy and composite FTP emissions are shown in Table 1-1. The table shows the value for each replicate, in the sequence in which the tests were performed. It also gives the average value for each configuration, and the percent difference between this average value and the average value for the six baseline replicates. Due to test variability, these percent differences do not give sufficient insight into the statistical significance of the results. Conventional tests for statistical significance were performed, and are presented in Section 5.4. Only nine cases showed statistical significance at the 95 percent confidence level, and they all involved emissions. In all nine cases, the significance was unfavorable; that is, the emissions were higher. As is discussed more fully in Section 5.4, the inherent variability of this data base considerably reduces the utility of the standard statistical test to depict the basic data trends. It was found that

TABLE 1-1. SUMMARY OF CHASSIS DYNAMOMETER TEST RESULTS

Configuration	Composite FTP				HWFET mpg	Steady-State, mpg	
	Gram/Mile			mpg		35 mph	55 mph
	HC	CO	NO_x				
Baseline	2.80	48.96	2.83	10.58	16.68	20.12	17.33
Baseline	2.49	26.24	3.21	11.91	16.47	18.25	16.28
Edelbrock Manifold	1.76	29.40	2.67	10.41	17.50	19.66	17.51
Edelbrock Manifold	1.98	24.74	3.36	10.97	17.92	19.29	17.72
(Average)	(1.87)	(27.07)	(3.02)	(10.69)	(17.71)	(19.47)	(17.62)
(Percent difference between average and average of six baselines)	(-16.5)	(-1.9)	(+20.3)	(-7.1)	(+2.8)	(+1.6)	(+1.6)
Edelbrock Manifold plus Hooker Headers	2.31	27.93	2.64	10.83	16.10	18.90	17.34
Edelbrock Manifold plus Hooker Headers	2.09	23.74	2.56	11.17	17.28	18.34	17.57
(Average)	(2.20)	(25.83)	(2.60)	(11.00)	(16.69)	(18.62)	(17.46)
(Percent difference between average and average of six baselines)	(-1.8)	(-6.4)	(+3.6)	(-4.4)	(-3.1)	(-2.8)	(+0.7)
Hooker Headers	1.97	35.47	4.33	11.19	16.61	18.46	19.04
Hooker Headers	1.77	24.92	4.02	12.46	17.87	18.89	17.80
(Average)	(1.87)	(30.19)	(4.18)	(11.82)	(17.24)	(18.67)	(18.42)
(Percent difference between average and average of six baselines)	(-16.5)	(+9.4)	(+66.5)	(+2.7)	(+0.1)	(-2.6)	(+6.2)
Baseline	1.72	15.88	2.19	12.08	17.85	19.43	18.00
Baseline	1.63	14.84	2.21	12.23	18.00	19.48	18.03

TABLE 1-1. SUMMARY OF CHASSIS DYNAMOMETER TEST RESULTS (Continued)

Configuration	Composite FTP				HWFET	Steady-State, mpg	
	Gram/Mile			mpg	mpg	35 mph	55 mph
	HC	CO	NO_x				
MSD, stock (0.050) Carburetor Jets	1.20	19.72	2.61	11.01	17.07	19.07	17.48
MSD, stock (0.050) Carburetor Jets	1.35	19.57	2.65	10.62	17.28	18.76	17.26
(Average)	(1.27)	(19.64)	(2.63)	(10.81)	(17.17)	(18.91)	(17.37)
(Percent difference between average and average of six baselines)	(-43.3)	(-28.8)	(+4.8)	(-6.1)	(-0.3)	(-1.3)	(+0.2)
MSD, lean (0.048) Carburetor Jets	1.51	15.46	2.41	11.27	17.12	18.39	16.84
MSD, lean (0.048) Carburetor Jets	1.45	16.08	2.36	11.28	17.35	18.66	17.01
(Average)	(1.48)	(15.77)	(2.38)	(11.27)	(17.25)	(18.52)	(16.92)
(Percent difference between average and average of six baselines)	(-33.9)	(-42.8)	(-5.2)	(-2.1)	(+0.2)	(-3.3)	(-2.4)
Baseline	2.99	44.26	2.14	10.66	16.87	18.58	17.20
Baseline	1.83	15.35	2.48	11.58	17.48	19.09	17.19
(Average of Six Baselines)	(2.24)	(27.59)	(2.51)	(11.51)	(17.22)	(19.16)	(17.34)
(1973 Certification Values, Corrected to 1975 FTP)	(2.4)	(14.0	(2.5)	(12.5)			

a useful way to portray the data was to identify those cases in which the mean of the two replicates for each test condition (such as the composite FTP fuel economy for the Edelbrock manifold) fell outside the 95 percent confidence interval for the population mean of the baseline configuration for that same test condition. These results are shown on Table 1-2, in which the FTP results are further broken down into results for each individual bag (test phase) of the FTP. The highlights of these tables are presented in the following discussion. It must be emphasized that these comments apply just to the data base of these tests. In view of the rather extreme variability which is sometimes encountered in chassis dynamometer testing, other factors must be taken into account before one can attempt to draw wide-ranging conclusions.

1.2.2.1 Edelbrock Intake Manifold

The Edelbrock inlet manifold showed a slight increase in average fuel economy for the HWFET and the steady-state speed conditions, but these are not statistically significant. It showed an average 7.1 percent decrease in composite FTP fuel economy, and this is large enough to appear in Table 1-2. It also showed higher NO_x for the composite FTP, due mostly to the contribution of the cold stabilized test phase.

1.2.2.2 Hooker Tuned Exhaust Headers

The Hooker headers were the only device which showed an increase in fuel economy at any test condition large enough to appear in Table 1-2. This occurred at the 55 mph steady-state road-load condition (6.2 percent higher than average baseline). The headers produced higher NO_x in all test phases except the 55 mph steady-state condition.

1.2.2.3 Combination of Edelbrock Manifold and Hooker Headers

The combination of the Edelbrock manifold and the Hooker headers did not show a significant increase in NO_x over the composite FTP, while each device tested separately did show an increase. Each of these two devices, individually and in combination, showed an increase in CO emission at the 55 mph steady state, by a factor of 2 to 3.

TABLE 1-2. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES

		EDELBROCK INLET MANIFOLD	EDELBROCK MANIFOLD + HOOKER HEADERS	HOOKER HEADERS	MSD-2 STANDARD AIR-FUEL (0.050)	MSD-2 LEANER AIR-FUEL (0.048)
FTP						
FE	1					
	2	X			X	
	3					
	Comp.	(X)				
HC	1				√	
	2				√	
	3					√
	Comp.				(√)	(√)
CO	1					
	2					
	3					
	Comp.					
NO_x	1			X		
	2	X		X		
	3			X		
	Comp.	(X)		(X)		
HWFET						
FE						
HC					√	√
CO						
NO_x				X	X	
35 MPH						
FE						
HC			X	X	√	√
CO				X		
NO_x				X		X
55 MPH						
FE				(√)		
HC						
CO		X	X	X		√
NO_x						

NOTE: Identification of those cases in which the mean of two replicates for the test device falls outside the 95 percent confidence interval for the population mean of the baseline configuration.

"X" denotes unfavorable significance (FE lower, or emissions higher)
"√" denotes favorable significance (FE higher, or emissions lower)
FTP Composite results, and all FE results from HWFET and steady states, are circled.

1.2.2.4 MSD-2 Ignition System

Although the MSD-2 device did not show any significant increase in fuel economy (the average values were in general slightly less than the average baseline values), it is of interest that this device showed a decrease in HC emissions in all tests except for the 55 mph steady state. With the stock carburetor fuel jets, the MSD-2 device showed higher NO_x in the HWFET; with the next leaner size jets, this device showed higher NO_x in the 35 mph steady-state condition. The latter case is not important, since the NO_x level in the 35 mph steady state is the lowest of any of the test phases (0.76 gr/mile average for the 6 baselines). The increased NO_x emission in the HWFET is of more importance, since the average baseline NO_x in gr/mile in the HWFET is comparable to the gr/mile NO_x generated in the FTP.

1.2.3 Discussion of Results

1.2.3.1 Impact of Test Conditions

The results of these chassis dynamometer tests provide the information which is required to supplement the analysis and engine dynamometer evaluations performed at earlier stages of this program. They supply the key input concerning the effects of selected retrofit devices on a vehicle operating over a wide, but controlled, range of driving conditions. In addition, they help answer the important questions concerning the effect of these devices on vehicle emissions. These results show that the FTP tends to be a "leveler" of fuel economy retrofit devices. By this it is meant that the FTP, with its demanding test conditions of cold start followed quickly by major accelerations, and its high frequency of idling in between relatively abrupt accelerations and decelerations, causes the fuel consumption to be governed primarily by such fundamental factors as engine displacement, vehicle inertia, and basic carburetion. The HWFET is also affected by these same factors, but to a lesser extent than the FTP.

1.2.3.2 Edelbrock Intake Manifold

The engine dynamometer tests described previously showed that the Edelbrock inlet manifold had a large beneficial effect on fuel economy at the lower steady-state speeds. These effects apparently were overridden in the FTP by the above-mentioned factors. These low speeds do not occur in the HWFET, so it is not surprising that the manifold did not show a significant improvement in this test. The manifold showed a slight, but not statistically significant, increase in the average fuel economy in the vehicle test at 35 mph steady state; this contrasts rather sharply with the 15 percent decrease in BSFC shown in the engine stand test at 35 mph road load.

1.2.3.3 Hooker Tuned Exhaust Headers

The tuned exhaust headers showed an improvement in fuel economy in the vehicle test at 55 mph steady-state conditions. The improvement was greater than that shown in the engine stand test at the same conditions. This result was expected, as this test condition represents near-optimum conditions for these tuned headers. This improvement occurred at the expense of significant increase in NO_x emissions, however. It is somewhat surprising that the headers did not reveal an improvement in vehicle fuel economy on the HWFET. The combination on the vehicle of the inlet manifold plus the headers did not reveal any improvement.

1.2.3.4 MSD-2 Ignition System

No significant fuel economy increase was predicted for the MSD-2 device based on the engine stand tests, and none was found in the vehicle tests. A key finding here was that this device, by itself, did not permit operation in the vehicle at significantly increased air-fuel ratio, without an objectionable degradation of driveability. The device manufacturers do not make such a claim, but this question was of interest because of the engine dynamometer tests at leaner air-fuel ratio. On the other hand, this ignition system showed a trend of reduced HC emissions, indicating that it accomplished one of its main purposes; namely, helping to promote improved combustion of residual cylinder gases.

1.2.3.5 Overview of Results

In conclusion, these vehicle chassis dynamometer tests do not show any basis, with respect to fuel economy improvement, for recommending wide-scale implementation of any of the retrofit devices tested herein. It must be stressed again that this conclusion applies within the constraints of the tests conducted. The test results indicate that caution is in order in regard to the use of tuned exhaust headers because of the possibility of increased NO_x emissions. Certain high-energy and/or multiple spark discharge systems, such as the MSD-2 device, may provide a decrease in HC emissions.

1.3 ULTRASONIC FUEL SYSTEM TESTS

1.3.1 Test Description

The Ultrasonic Fuel Induction System is a computer-regulated fuel delivery system, with ultrasonic atomization of the fuel just prior to induction into the intake manifold. The intended function of the device is to control fuel flow so as to maintain a fixed, lean air-fuel ratio over a range of vehicle operating conditions, and provide a controlled degree of fuel enrichment for acceleration modes. The device was installed in a 1972 Plymouth Duster with 225 CID slant-six engine, with automatic transmission. A Delta Mark Ten capacitive discharge system was also installed on the vehicle.

The test plan consisted of two replicate test series for each of three configurations. The first configuration consisted of the fully operational ultrasonic system. In the second, the ultrasonic vibrator was disconnected. The reason for this was to distinguish between the effects of air-fuel ratio control and fuel atomization for different operating conditions, such as the cold and hot start portions of the FTP. The inventors had previously suggested the possibility of operating without the ultrasound after the engine became thoroughly warmed up.

The third test configuration comprised complete deactivation of the fuel induction system, and replacement with the stock carburetor. In this configuration, the carburetor was adjusted according to the vehicle manufacturer's recommended procedure, with no other changes to any vehicle or engine parameter.

Each configuration was tested twice by the 1975 FTP, the EPA HWFET, and at 35 mph and 55 mph steady-state speeds.

1.3.2 Test Results

1.3.2.1 Fuel Economy Effects

With the ultrasonic device fully operational, the vehicle fuel economy was approximately 3 percent poorer than the stock vehicle on the FTP, and approximately 2 percent better on the Highway Driving Cycle. It had a 6 percent improvement at 35 mph, and 3 percent improvement at 55 mph. With the ultrasound disconnected, the results were not greatly different, except at the 55 mph conditions, where the fuel economy was 3 percent poorer than the baseline vehicle.

It is likely that the projected fuel economy claims for this device were in error because of the condition of the stock carburebor to which the device had been previously compared. When installed for baseline tests, the stock carburetor was flooding badly and could not be adjusted to give factory settings at idle conditions. Therefore, a new stock carburetor was used for the baseline tests.

1.3.2.2 Emissions Effects

With the ultrasonic device operational, there were significant reductions in HC and CO (23 and 35 percent, respectively). These results would be consistent with a more uniform fuel-air mixture promoting a higher flame temperature, but without a sufficient increase in air-fuel ratio to bring about a reduction in NO_x. The device inventor found it necessary in these tests to adjust the on-board computer setting to provide a somewhat richer mixture than the prior setting, in order for the car to be able to follow the Federal Driving Cycle.

1.3.2.3 Overview Comments

It should be noted that the small number of tests run does not permit a statistical determination of the relative efficacy of this device. On the basis of the tests made, however, there do not appear to be any significant differences in fuel economy, particularly in view of normal test measurement accuracy limitations.

SECTION 2
INTRODUCTION

2.1 BACKGROUND, OBJECTIVES, AND SCOPE

The recent embargo on petroleum exports to the United States by the oil-producing countries of the Middle East amply demonstrated that automotive fuel shortages in the United States can occur at any time unless and until the United States becomes self-sufficient with regard to automotive fuel needs. As a result, many concerned people have postulated various methods for reducing automotive fuel consumption in order to lessen the national demand for petroleum.

In particular, the United States Department of Transportation has been the recipient of many letters and other communications offering or recommending different carburetion approaches which are claimed to offer significant fuel economy advantages over the standard or conventional carburetor as used in gasoline-fueled spark ignition engines. Many conflicting claims have been made regarding fuel economy advantages. In addition, some of the communicants have expressed the opinion that the automotive industry might be "suppressing" the development or use of advanced or novel carburetion techniques in one manner or another.

In addition to carburetors, there has also been a large number of other devices offered for sale as retrofit or add-on units for automobiles and advertised to improve fuel economy (reduce fuel consumption). In most cases, test data to verify the degree of fuel economy improvement claimed have not been immediately available nor technically substantive in nature.

Therefore, the present study was initiated with the objectives of evaluating the potential of used car and light truck retrofit devices for reducing fuel consumption in a timely, economic, and effective manner; of providing the information necessary for the federal government to determine if it should encourage the use of such retrofit concepts; and of offering a plan for DOT to develop any needed additional information.

These objectives were to be met by means of (a) the identification and characterization of retrofit devices, ideas, concepts, and/or fuel modifications which have been postulated to offer meaningful reductions in automotive fuel consumption; (b) the analysis of each such promising device or concept with regard to operational effectiveness modes and resultant fuel economy gains, degree of applicability to the existing vehicle population, and concomitant side effects; (c) an initial comparative evaluation of contending retrofit concepts to identify the most promising concept(s) in terms of effectiveness, applicability, availability, economics, and emissions; (d) the definition of a test plan for experimental verification of selected retrofit devices; (e) a verification test program; and (f) a final evaluation of relative merit with regard to fuel economy improvement potential based on test program results.

The study was limited in scope to those retrofit devices/concepts/techniques which were readily identifiable and already available or which could reasonably be expected to be available in the immediate future. Thus, mere ideas or approaches which have had little or no development activity to bring them to fruition were excluded from consideration. In the main, the concepts included in the study are those for which a hardware item or system has been built or is known to be offered for sale.

The program was divided into two phases to aid in implementation. Phase I, the analytical and preliminary evaluation phase, encompassed items (a) through (d) above, and was completed and reported in 1975[1]. Phase II, the testing and final evaluation phase, is the subject of the present report.

2.2 SUMMARY OF PHASE I RESULTS

Over twenty representative classes of retrofit devices/concepts/techniques, including over 130 specific items, were examined in Phase I of this study. The spectrum of devices examined included: carburetors; acoustic and mechanical atomizers; lean-bleed devices; vapor injectors; fuel modifications; inlet manifolds; ignition systems; drivetrain components; drag reduction techniques; driver aids; cooling fans; valve timing modifications; tuneups; compression ratio increases; exhaust-related systems; and engine oils, oil additives, and filters.

A very brief summary of the highlights of the Phase I analysis and preliminary evaluation is presented in Table 2-1 to give a basis of perspective to the Phase II results presented herein. The basic classes of devices are listed in the left-hand column of the table. Each such class was evaluated as to fuel economy improvement potential in the four categories shown:

a. Negative (- to 0 percent)

b. Negligible (0 to 4 percent)

c. Modest (5 to 14 percent)

d. Substantial (15 percent and above)

These ratings were based upon available test data plus analyses of the general operational principles of a given device and its possible effects on spark ignition engine operation in order to substantiate or explain the test data.

Carburetors providing improved fuel atomization and/or lean operation were rated in the "modest" category; two such carburetors were selected for Phase II tests; however, only one was available for test purposes.

Below-carburetor atomizers of the screen type were judged to have a "negligible" effect, while acoustic atomizers were rated in the "modest" category. The Post Carburetor Atomizer (PCA) was initially selected for Phase II tests, but dropped when it was not available for the engine selected for Phase II evaluations.

Lean-bleed systems were placed in the "negligible" category, although it was realized that some pre-controlled cars with richer air-fuel ratios could have a "modest" increase in fuel economy.

Vapor injectors, fuel additives, fuel mixtures, and fuel pressure regulators were rated in the "negligible" column.

The inlet manifold test data were somewhat mixed, with Edelbrock data indicating gains in the "modest" category. Both Offenhauser and Edelbrock inlet manifolds were selected for Phase II tests.

Capacitive and inductive high energy ignition systems were judged to have "negligible" effects on maintained vehicles, but it was also felt that cars with leaner air-fuel ratios could obtain "modest" benefits. A capacitive discharge system, the multiple spark system, was selected for Phase II testing.

TABLE 2-1. COMPARISON OF CONCEPTS/DEVICES FUEL ECONOMY POTENTIAL

Class/Device	Fuel Economy Improvement Potential* Negative to 0%	Negligible 0 to 4%	Modest 5 to 14%	Substantial 15% and Above
Carburetors (selected ones)			X	
Atomizers		Screens	Acoustic PCA	
Lean-Bleed Systems		X	Some pre-controlled cars could have modest increase	
Vapor Injectors		X		
Fuel Modifications				
Fuel Additives		X		
Fuel Mixtures		X		
Inlet Manifolds		Offenhauser Data	Edelbrock Data	
Pressure Regulators		X		
Fuel Pre-agitator	X			
Ignition Systems				
Capacitive Discharge		On maintained vehicles	On cars with lean air-fuel ratios	
Electronic Inductive		On maintained vehicles	On cars with lean air-fuel ratios	
Others		X		
Emission Control Retrofits	X			
Drivetrain				
Tires			Radial tires	
Transmissions			Truck automatic transmissions	
Rear Axle Gear Ratios			X	Highway driving
Overdrive Units			X	Highway driving
Drag Reduction Devices		X	Highway driving	
Driver Aids		←	Indeterminate	→
Flexible Cooling Fans		X		
Valve Timing		X		
Tuneups			X	
Compression Ratio Increase			X - Not recommended	
Tuned Exhaust Systems			X	
Dual Exhaust Systems		X		
Exhaust Cutout			X - Not recommended Illegal in some States	
Turbochargers	X - With same eng			With reduced eng CID
Engine Oil			May be possible	
Engine Oil Additives			May be possible	
Engine Oil Filter		X**		
Tampering with ECSs	← X	→		
Suggested Combinations				
Inlet Manifold and Tuned Exhaust			X	Possible
Carburetor Plus CD Ignition - MSD, in particular			X - Lean air-fuel ratios	

* Based on present state of the art and available data

** Prevents performance degradation over lifetime

Radial tires, new 4- and 5-speed truck automatic transmissions, lower rear axle ratios, and overdrive units were rated in the "modest" category. Both overdrives and axle ratio changes can result in substantial improvements during highway driving alone. In all cases, the available data were considered sufficient for evaluation purposes.

Drag reduction devices were rated in the "negligible" category for city and mixed driving and in the "modest" category for highway driving. Tests of these devices were beyond the scope of Phase II activities.

The fuel improvement potential of driver aid devices was judged to be indeterminate, based on data acquired in Phase I. These devices were explored in greater detail in a subsequent study for DOT[2].

Flexible cooling fans and valve timing modifications were rated in the "negligible" category.

The improvement due to tuneups was rated in the "modest" category. The activities required to more accurately quantify such effects were beyond the scope of Phase II.

Although it was recognized that compression ratio increases could result in "modest" improvements, they were not recommended because of possible emissions effects and increased octane requirements.

Tuned exhaust systems were rated in the "modest" category and were selected for Phase II testing. Dual exhaust systems were judged to have negligible effects; exhaust cutouts, which could provide a "modest" improvement, were not recommended because of noise and illegality in some states.

Turbochargers require an engine change to a smaller displacement (CID) in order to achieve meaningful fuel economy improvements. The available data are adquate for evaluation purposes.

Engine oils and oil additives were felt to have "negligible" effects on fuel economy, based on the data on hand. However, it was recognized that

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[2] "Survey of Driver Aid Devices for Improved Fuel Economy," Report No. DOT-TSC-OST-76-45, 1976

"modest" benefits may be possible with improved formulations. The type and amount of testing required to quantify such benefits were beyond the scope of Phase II efforts.

Finally, the analyses and available data suggested that two combinations also appeared attractive. They were the inlet manifold plus tuned exhaust and high energy ignition plus lean air-fuel ratios. These combinations were selected for Phase II evaluation.

Those devices which were selected for testing in Phase II of the program were those which (a) were considered to have the potential for fuel economy improvement of 5 percent or more, (b) required additional confirmatory testing to adequately establish their fuel economy improvement potential, and (c) were available and within the scope of Phase II efforts insofar as tests with and without the device were considered sufficient to establish their relative merit. These devices included: Dresserator carburetor, Ultrasonic Fuel System carburetor, Edelbrock and Offenhauser high-velocity intake manifolds, Hooker and Hedman tuned exhaust systems, MSD capacitive discharge ignition system, and the combination of intake manifold plus tuned exhaust system.

The basic elements of the Phase II test program are described in Section 3; test results are presented in Sections 4, 5, and 6.

SECTION 3

BASIC ELEMENTS OF PHASE II TEST PROGRAM

The basic elements of the Phase II test program plan are presented in overview in Table 3-1. Part 1 of the program was conducted by the University of Michigan, Ann Arbor, Michigan, and consisted of steady-state engine dynamometer tests of selected retrofit devices on a 1973 350 CID Chevrolet engine. The purpose of these tests was to "screen" the devices for fuel economy improvement potential prior to later chassis dynamometer tests, and to provide valuable insight as to the operating conditions under which fuel economy improvements (if any) were made.

Parts 2 and 3 of the program consisted of vehicle chassis dynamometer tests of complete vehicle systems and were conducted by Olson Laboratories at their Livonia, Michigan test facilities. These tests were performed to provide an overall measure of fuel economy improvement potential under both the cold-start conditions of the 1975 FTP and the warmed-up engine conditions of the EPA Highway Driving Cycle. Steady-state cruise tests at 35 and 55 mph conditions were included for comparison with the engine dynamometer test results at these same operating conditions. The chassis dynamometer tests were also necessary to determine the impact of the various retrofit devices on vehicle exhaust emissions.

Part 2 of the program consisted of tests of the Ultrasonic Fuel Induction System. This test series was selected to represent the class of advanced carburetion techniques examined in Section 3.1 of the Phase I Analysis and Preliminary Evaluation report[1]. Tests of the Dresserator Inductor System were originally planned also, but were not made due to unavailability of the Dresser carburetor.

Part 3 of the program consisted of a series of tests of a 1973 Chevrolet Impala incorporating a two-Venturi Edelbrock intake manifold, a Hooker tuned exhaust header, and the MSD ignition system in conjunction with lean air-fuel ratio settings. These devices were selected from the items

TABLE 3-1. OVERVIEW OF PHASE II TEST PROGRAM PLAN

University of Michigan Ann Arbor, Michigan	Facility	Olson Laboratories Livonia, Michigan
Steady State - Engine Dyno	Test Mode	1975 FTP - Chassis Dyno
Device		Device
• Multiple Spark Discharge System • High Performance Intake Manifold Edelbrock Streetmaster Offenhauser Dual Port • Tuned Exhaust Headers Hooker Hedman • Combined H.P. Intake Manifold Plus Tuned Exhaust Headers	Retrofit Test Devices	• Ultrasonic Fuel Induction System (A. K. Thatcher, Merritt Island, Fla.) • Promising Devices from University of Michigan Screening Test Program

tested in the University of Michigan screening test program. The Offenhauser dual-port intake manifold was not tested because it was not available in the two-Venturi configuration. Both Hooker and Hedman tuned exhaust manifolds were similar in performance, based on the University of Michigan test results; the Hooker unit was selected because of the ready availability of comparative published test data in the Phase I report.

The specific details of each of these parts of the overall Phase II test program are delineated in the following sections. The physical and operational characteristics of each retrofit device are defined in detail in the Phase I report and are not repeated in this volume.

SECTION 4

ENGINE DYNAMOMETER TEST RESULTS

A number of screening and characterization tests were conducted in the Automotive Engineering Laboratory at the University of Michigan. These tests consisted of steady-state dynamometer tests of a 1973 350 CID Chevrolet engine, with and without retrofit devices.

The purpose of this portion of the program was to provide a screening of potentially beneficial retrofit devices. Those devices which showed most promise in this task were to be tested on a vehicle in a subsequent phase. Vehicle tests on a chassis dynamometer in accordance with EPA test procedures are very time-consuming and expensive. It was accordingly necessary to restrict these tests to those devices which could provide some preliminary justification for their inclusion.

4.1 TEST PLAN

Testing was divided into two main categories: component and air-fuel ratio effects. In the first category, several retrofit components were tested separately on a Chevrolet 350 CID V-8 engine at steady-state road-load cruise conditions of 25, 35, 45, 55, and 65 mph, and WOT conditions at 35 and 55 mph. The BSFC was measured at each condition. A baseline condition, with the engine in stock condition in all respects, was run before and after each test device.

The components tested were two intake manifolds, two tuned exhaust systems, and a multiple spark capacitive discharge ignition system. The intake manifolds were an Edelbrock Streetmaster (Edelbrock Equipment Company, El Segundo, California), tested with both two- and four-barrel carburetors, and an Offenhauser four-barrel unit* (Offenhauser Sales Corporation, Los Angeles, California). The exhaust headers were obtained from Hooker Industries, Ontario, California, and from Hedman Manufacturing

*Unit was available only in four-barrel configuration

Company, Culver City, California. The ignition system device was the MSD-2 multiple spark capacitative discharge system, sold by the Autotronic Controls Corporation, El Paso, Texas. The overall sequence of test runs for this first phase of the engine dynamometer tests is shown in Table 4-1.

At the conclusion of the individual component tests, a combination of two devices was selected for an additional series of tests. As described subsequently, the combination selected was the Edelbrock two-barrel (2-V) intake manifold and the Hooker tuned-exhaust headers.

In the second category of engine dynamometer tests, the effects of air-fuel ratio and ignition system were investigated. At steady-state road-load speeds of 35 and 55 mph, the air-fuel ratio was varied from approximately 15 to approximately 20 for each of three ignition systems. These were the stock breaker point ignition system, the MSD-2 device, and the MRI device, a product of Labtronics Company, Ypsilanti, Michigan. Each configuration was further tested at three spark plug gaps; 0.035 inch (stock), 0.060, and 0.080, and at two conditions of spark timing: stock timing and MBT timing. The BSFC was measured for each condition, and plots of BSFC vs. air-fuel ratio were constructed for parameters of road-load speed, timing, and plug gap.

4.2 TEST PROCEDURE

Testing was conducted in an engine dynamometer cell at the University of Michigan Automotive Laboratory. The engine used was a 1973 Chevrolet 350 CID V-8, connected to an electric absorption dynamometer. The component tests were all made at the engine manufacturer's specified tune conditions of breaker point dwell angle, ignition timing, and carburetor idle adjustment. In all tests, the exhaust gas recirculation (EGR) circuit was in operation, as was the air injection pump. In this engine, the air injection ports are located in each exhaust stack in the immediate vicinity of the exhaust manifold. The tuned-exhaust headers did not have air injection ports; in these cases, the air injection pump simply discharged into the atmosphere. This had no significant effect on engine power, and exhaust emission measurements were not performed during these engine dynamometer tests.

TABLE 4-1. RUN SEQUENCE FOR UNIVERSITY OF MICHIGAN TESTS (COMPONENT TEST SERIES)

Test	Carburetor
Baseline	2-V
MSD	2-V
Baseline	2-V
Edelbrock Manifold	2-V
Baseline	2-V
Hooker Exhaust Headers	2-V
Baseline	2-V
Hedman Exhaust Headers	2-V
Baseline	2-V
Baseline	4-V
Edelbrock Manifold	4-V
Baseline	4-V
Offenhauser Manifold	4-V
Baseline	4-V
Hi Performance Manifold Plus Exhaust Headers	4-V or 2-V
Baseline	4-V or 2-V

A valve in the facility exhaust line was used to maintain the engine exhaust pressure for each test condition at a value representative of that which would occur in a vehicle.

Volumetric fuel flow was measured directly by a burette method. Temperature of the fuel was measured, and use of the measured density vs. temperature relationship of the gasoline provided the fuel mass flow rate for each test condition. For the air-fuel ratio variation tests, inlet air mass flow rate was measured by means of a General Motors air cart, which is a calibrated orifice device.

The relationship between road load, engine rpm, and vehicle speed was derived from powertrain data for a 1973 Chevrolet Impala containing this engine, with a 3-speed automatic transmission, rear axle ratio of 2.73, and G78-15 tires. These were the same vehicle parameters utilized in subsequent vehicle chassis dynamometer testing (Section 5).

4.3 COMPONENT TEST RESULTS

4.3.1 Intake Manifold Tests

Two intake manifolds, the Edelbrock Streetmaster (Figure 4-1) and the Offenhauser Dual-Port (Figure 4-2), were tested. The Edelbrock was suitable for testing in both the 2-V and 4-V configurations, while the Offenhauser Dual-Port was limited to 4-V operation. Table 4-2 lists the test results as reported by the University of Michigan.

Figure 4-3 graphically depicts the results of steady-state engine dynamometer tests for the Edelbrock 2-V unit. The data is shown as a function of the steady-state road-load speed condition. The vertical scale is the change in BSFC over baseline tests without the device installed. Percent decreases in BSFC, above the 0 or baseline, therefore represent areas of fuel economy improvement.

This is a 2-V carburetor configuration. As can be noted, 14 to 15 percent improvements were obtained in the 25-35 mph range, with essentially no change at other speed conditions. Wide-open throttle tests at 35 and 55 mph show a reversed trend, with the largest gain (approximately 5 percent) at 55 mph.

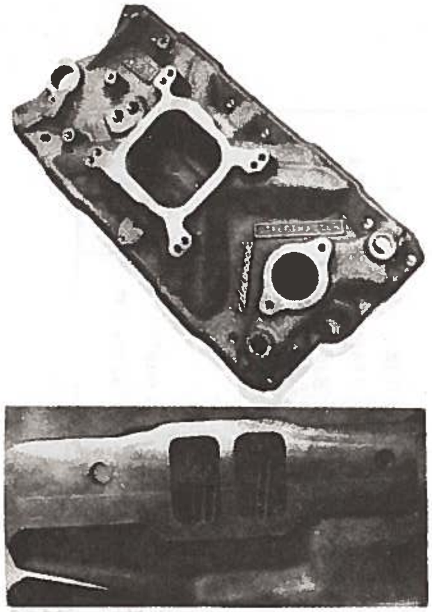
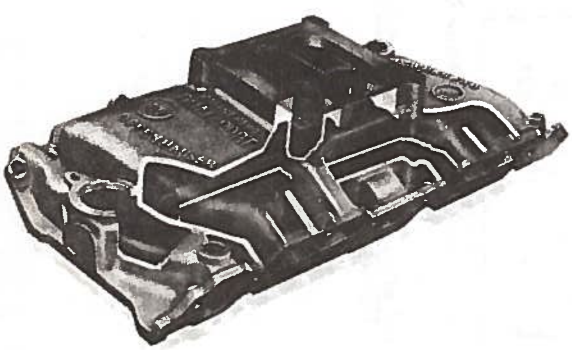
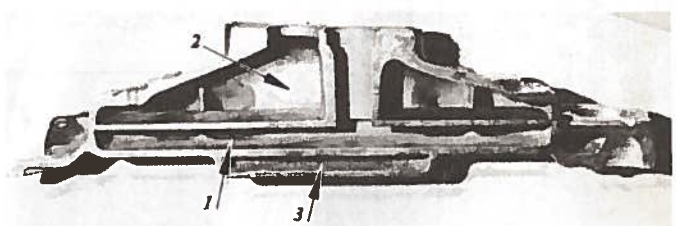


FIGURE 4-1. VIEW OF EDELBROCK STREETMASTER INLET MANIFOLD (Company Advertisement)





Cutaway view discloses some of the little intricacies of the Dual-Port. Arrow number one is the primary mixture passage. Arrows number two and three are the secondary passage and heat riser passage, respectively. Notice how the secondary passages are isolated from engine valley heat.

FIGURE 4-2. CUTAWAY VIEW OF OFFENHAUSER DUAL-PORT 360 INLET MANIFOLD (Company Advertisement)

TABLE 4-2. INTAKE MANIFOLD TEST RESULTS (University of Michigan Engine Dynamometer Tests)

	BSFC at Road Load Test Conditions*							
Speed, mph	Baseline Test (2-V)	Edelbrock Manifold (2-V)	Baseline Test (2-V)	Baseline Test (4-V)	Edelbrock Manifold (4-V)	Baseline Test (4-V)	Offenhauser Manifold (4-V)	Baseline Test (4-V)
Cruise Test Conditions								
25	1.317	1.139(+14%)	1.336	1.145	1.085(+6%)	1.154	1.192(-5%)	1.116
35	1.108	0.945(+15%)	1.126	1.031	1.037(-1%)	1.031	0.974(+5%)	1.021
45	0.881	0.876(+1.5%)	0.898	0.866	0.887(-3%)	0.862	0.819(+4%)	0.852
55	0.750	0.752(0%)	0.754	0.738	0.751(-2%)	0.734	0.723(+1%)	0.730
65	0.656	0.650(+2%)	0.666	6.673	0.669(0%)	0.670	0.666(0%)	0.664
WOT Test Conditions								
35	0.605	0.557(+3%)	0.540	0.554	0.584(-1%)	0.606	0.608(+1%)	0.621
55	0.618	0.599(+5%)	0.640	0.522	0.460(+18%)	0.597	0.525(+13%)	0.613

*Numbers in parentheses are percent differences from baseline values:

$$\text{Percent Diff.} = \frac{\text{(Average of before and after baselines) - Device}}{\text{(Average baseline)}}$$; rounded to nearest percent

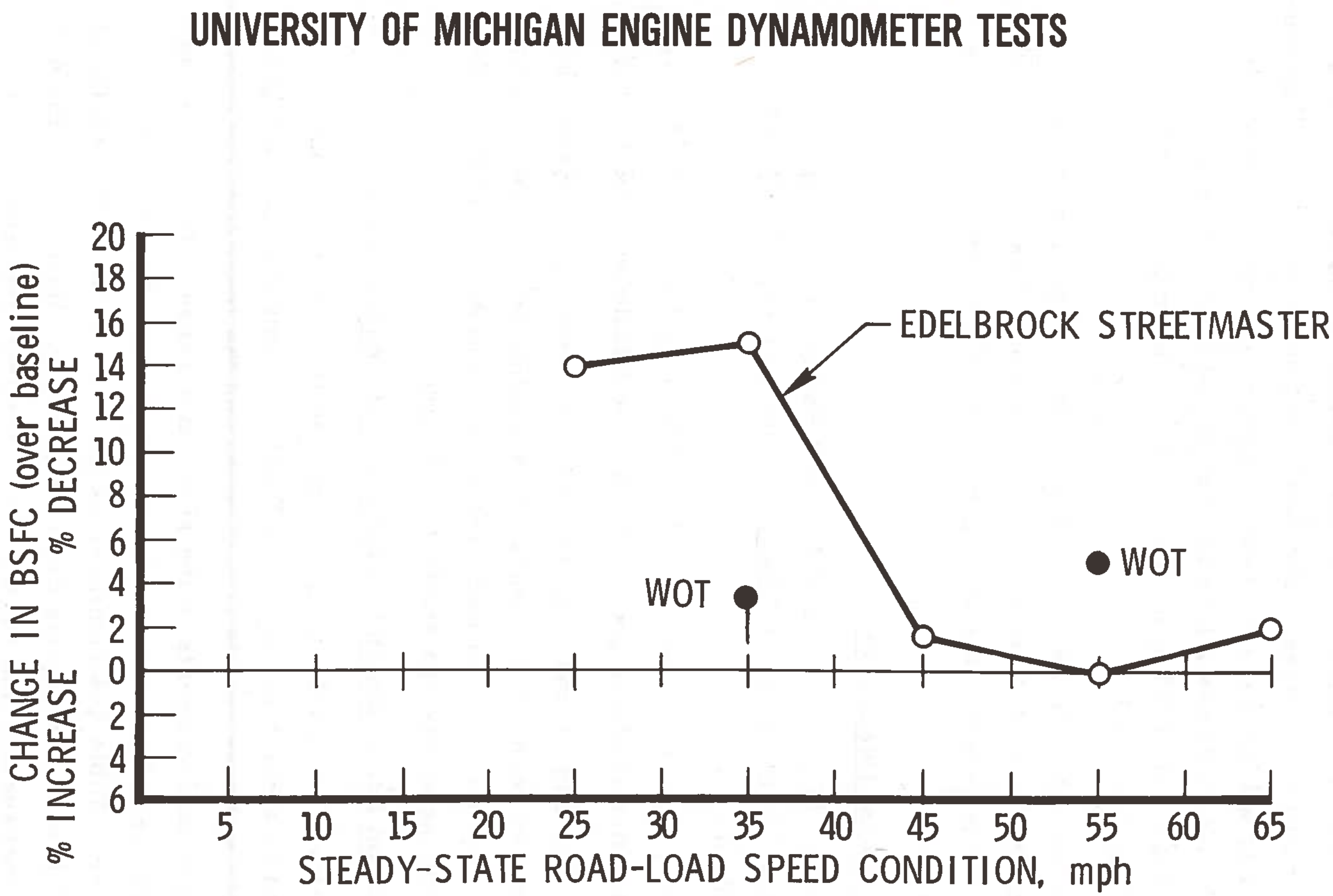


FIGURE 4-3. INTAKE MANIFOLD TEST RESULTS 2-V CONFIGURATION

The Edelbrock and the Offenhauser Dual-Port manifolds test results in the 4-V configuration are shown in Figure 4-4. The Offenhauser unit was available only as a 4-V unit. Here, the general trends of the two units are nearly reversed, or mirror images. The Edelbrock unit has a small improvement at 25 mph and small losses in fuel economy over the rest of the speed range. The Offenhauser unit has a loss at 25 mph and slight gains over the rest of the speed range. At WOT conditions, significant improvements at 55 mph were noted for both units.

These general trends were not considered to imply significant improvements over the stock 4-V manifold configuration. Therefore, the 2-V Edelbrock manifold was selected for testing in a 1973 Chevrolet Impala on a chassis dynamometer.

4.3.2 Tuned Exhaust Header Tests

Both Hooker (Figures 4-5 and 4-6) and Hedman tuned exhaust headers were tested. Table 4-3 lists the test results as reported by the University of Michigan.

Figure 4-7 depicts the engine dynamometer test results. The ordinates here are the same as shown previously for the Edelbrock inlet manifold.

Both Hooker and Hedman tuned exhaust systems showed very similar trends: poorer fuel economy at steady-state speeds below 50 mph. Small improvements of 2 to 3 percent are indicated above 50 mph. At WOT conditions, 4 to 5 percent increases are shown for 55 mph.

4.3.3 Combination Intake Manifold Plus Exhaust Header Tests

The Edelbrock 2-V inlet manifold and the Hooker tuned exhaust system were tested as a combination. The Edelbrock unit showed the highest improvement trends at lower speeds (25-35 mph) and the tuned exhaust systems indicated slight improvements in the 55-65 mph range. The Hooker unit was selected merely because there are Edelbrock plus Hooker comparative data in the literature. Table 4-4 summarizes the results of the University of Michigan tests and Figure 4-8 depicts them graphically. Here, the combined systems showed a measurable and consistently beneficial fuel economy trend across the speed range. This specific configuration was selected for chassis dynamometer tests in a 1973 Chevrolet Impala.

TABLE 4-3. TUNED EXHAUST HEADER TEST RESULTS (University of Michigan Engine Dynamometer Tests)

BSFC at Road Load Test Conditions*					
Speed, mph	Baseline Test (2-V)	Hooker Exhaust (2-V)	Baseline Test (2-V)	Hedman Exhaust (2-V)	Baseline Test (2-V)
Cruise Test Conditions					
25	1.288	1.305 (-2%)	1.271	1.350 (-5%)	1.291
35	1.035	1.093 (-6%)	1.026	1.113 (-8%)	1.033
45	0.874	0.882 (-2%)	0.854	0.885 (-3%)	0.870
55	0.751	0.738 (+2%)	0.754	0.735 (+3%)	0.754
65	0.647	0.641 (+2%)	0.662	0.650 (+2%)	0.666
WOT Test Conditions					
35	0.540	0.536 (+1%)	0.543	0.554 (-2%)	0.546
55	0.580	0.557 (+6%)	0.591	0.572 (+4%)	0.602

*Numbers in parentheses are percent differences from baseline values:

$$\text{Percent Diff.} = \frac{\text{(Average of before and after baselines) - Device}}{\text{(Average baseline)}}\text{; rounded to nearest percent}$$

UNIVERSITY OF MICHIGAN ENGINE DYNAMOMETER TESTS

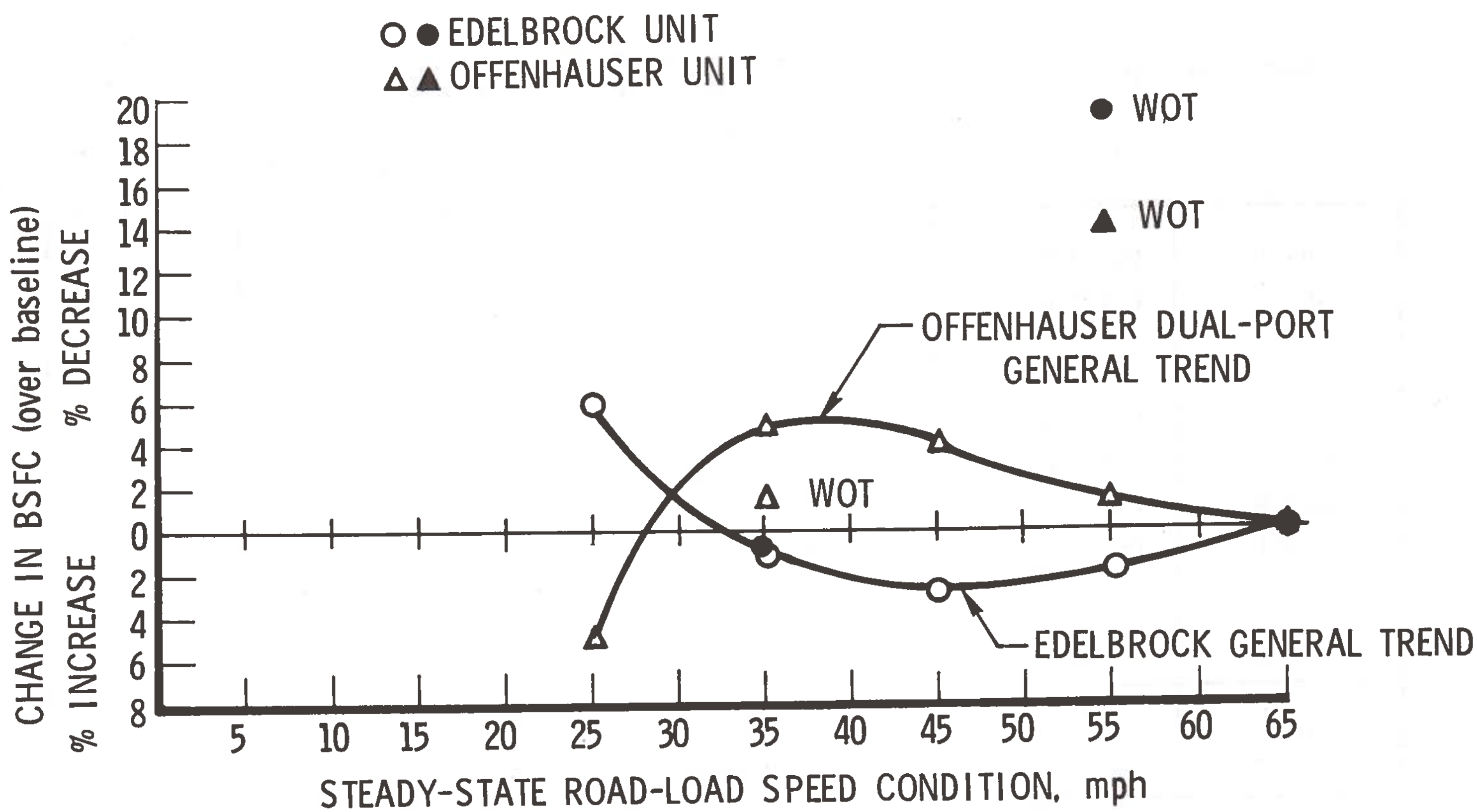


FIGURE 4-4. INTAKE MANIFOLD TEST RESULTS 4-V CONFIGURATION

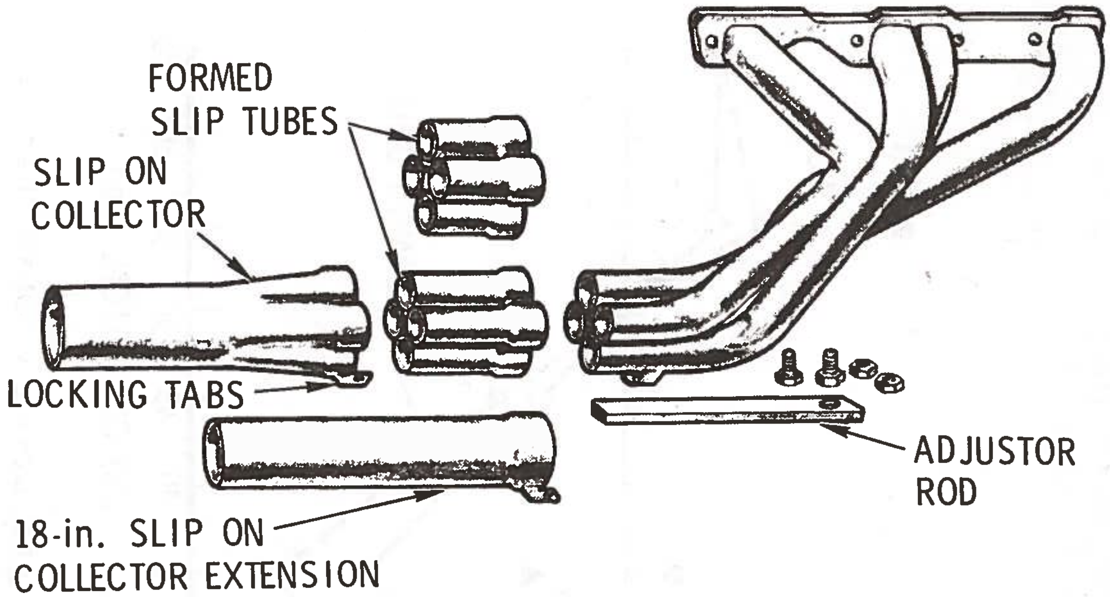


FIGURE 4-5. HOOKER ADJUSTABLE HEADER KIT

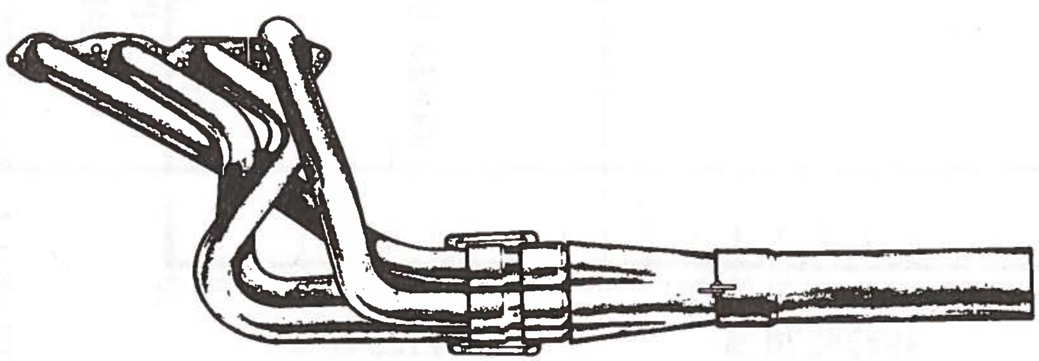


FIGURE 4-6. HOOKER ADJUSTABLE HEADER ASSEMBLED

UNIVERSITY OF MICHIGAN ENGINE DYNAMOMETER TESTS

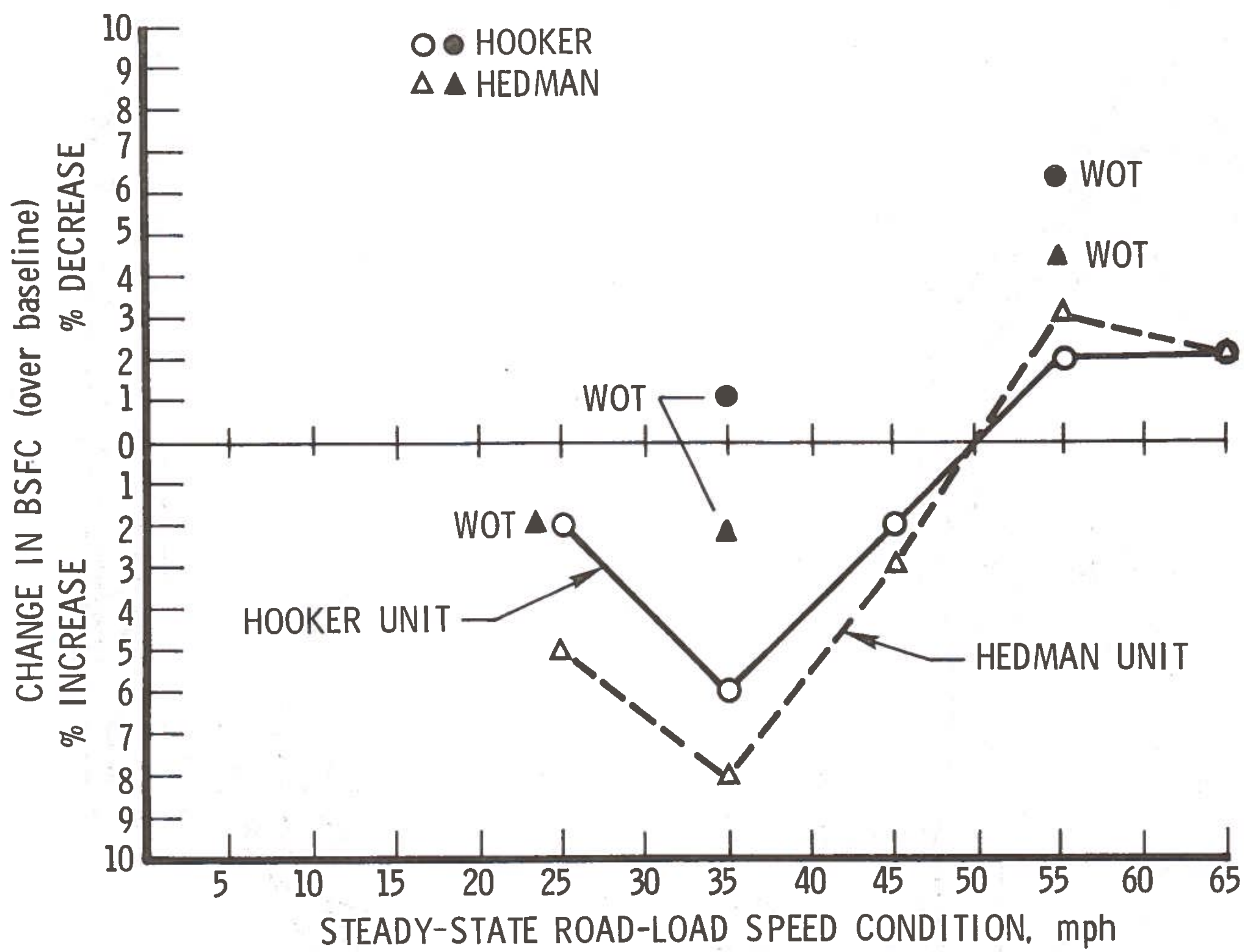


FIGURE 4-7. TUNED EXHAUST HEADER TEST RESULTS – 2-V CONFIGURATION

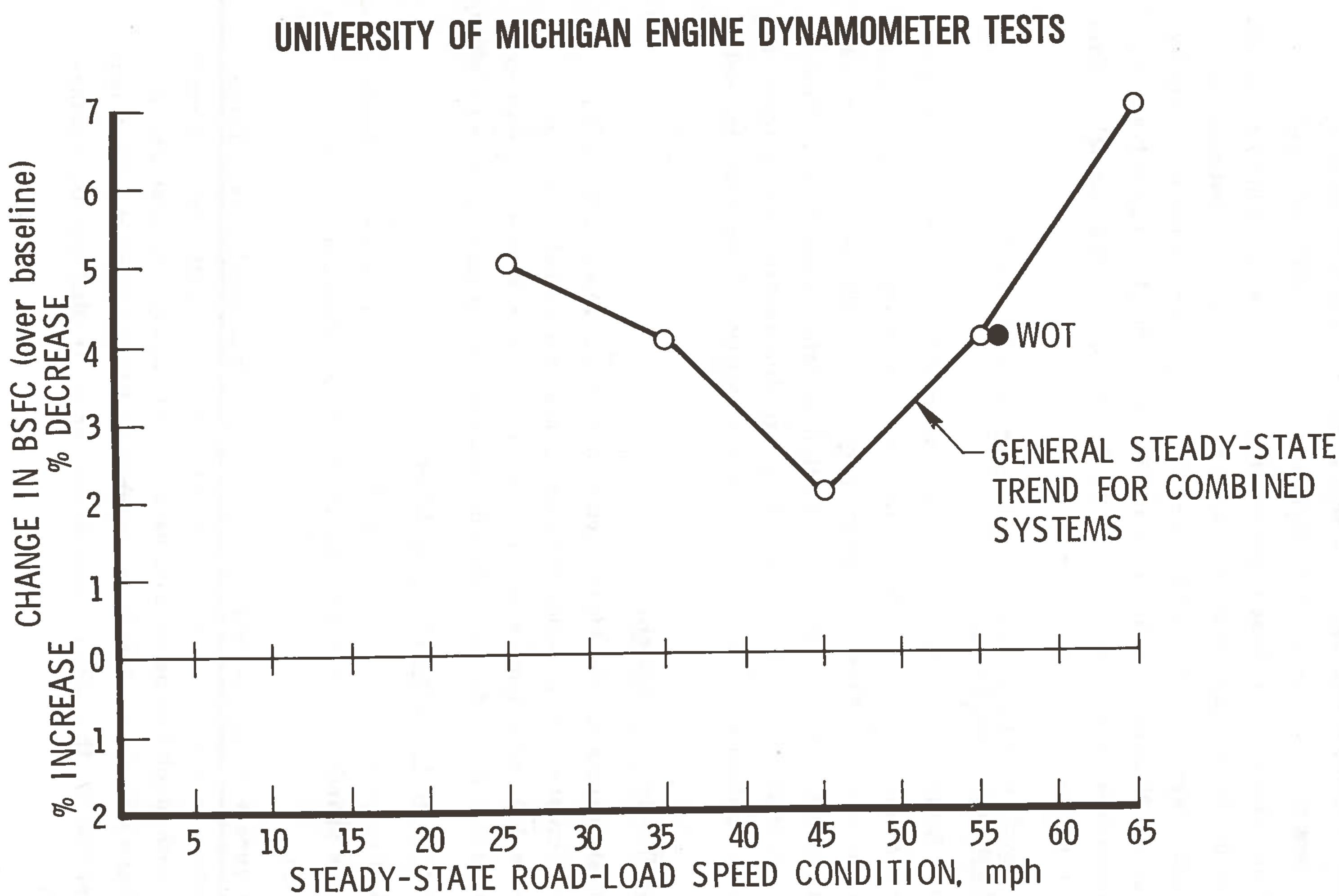


FIGURE 4-8. EDELBROCK MANIFOLD PLUS HOOKER TUNED EXHAUST TEST RESULTS – 2-V CONFIGURATION

The 9 percent decrease in BSFC at the 35 mph WOT condition (Table 4-4) may be due to an exceptionally low baseline BSFC of 0.499; the other baseline values at this test condition were in the range of 0.54 to 0.605. The raw data for the suspect baseline value were reexamined, but nothing could be found in error. This difference, although large, is not statistically significant at the 95 percent confidence level. Accordingly, Table 4-4 lists the as-measured results for the 35 mph WOT condition. This anomalous data point falls off the scale of Figure 4-8.

4.3.4 Capacitive Multiple Spark Discharge Ignition System and Lean Air-Fuel Ratio Tests

The MSD-2 multiple spark, high-energy capacitive discharge ignition system manufactured by the Autotronic Controls Corporation was evaluated by two test series. First, it was merely added to the stock 2-V engine test configuration to note the effects of ignition system change alone. Next, the MSD-2 was compared with a conventional ignition system and an additional multiple spark ignition system to evaluate their ability to burn lean air-fuel mixtures.

4.3.4.1 MSD-2 Ignition System

Test results for the MSD-2 ignition system, when added to the stock 2-V test engine configuration with no change in air-fuel ratio, are shown in Table 4-5 and Figure 4-9. As was predicted in Phase I, the gains are minimal and in the order of 1 percent, except for the point at 35 mph WOT.

4.3.4.2 Air-Fuel Ratio and Plug Gap Effects

Additional tests were made at 35 and 55 mph steady-state road-load conditions to indicate possible effects at lean air-fuel ratios and advanced timing.

Figure 4-10 illustrates the results at 35 mph conditions. Three ignition systems, stock, MSD, MRI, and three spark plug gap settings were employed at both stock timing conditions and MBT timing. Except where indicated, there was no displayable difference in BSFC among the three ignition systems; that is, the effect shown in the curves is plug-gap and timing-related only.

TABLE 4-4. TEST RESULTS - EDELBROCK MANIFOLD PLUS HOOKER HEADERS (University of Michigan Engine Dynamometer Tests)

BSFC at Road Load Test Conditions*		
Speed, mph	Baseline	Edelbrock plus Hooker
Cruise Test Conditions		
25	1.338	1.274 (+5%)
35	1.054	1.017 (+4%)
45	0.874	0.859 (+2%)
55	0.749	0.719 (+4%)
65	0.679	0.629 (+7%)
WOT Test Conditions		
35	0.499	0.544 (-9%)
55	0.580	0.556 (+4%)

*Numbers in parentheses are percent differences from baseline values.

TABLE 4-5. MSD-2 IGNITION SYSTEM TEST (University of Michigan Engine Dynamometer Tests)

BSFC at Road Load Test Conditions*			
Speed, mph	Baseline (2-V)	MSD-2 (2-V)	Baseline (2-V)
Cruise Test Conditions			
25	1.298	1.293 (+1%	1.317
35	1.093	1.095 (+1%)	1.108
45	0.881	0.879 (0%)	0.881
55	0.763	0.750 (1%)	0.750
65	0.664	0.664 (+1%)	0.656
WOT Test Conditions			
35	0.588	0.557 (+7%)	0.605
55	0.609	0.605 (+1%)	0.618

*Numbers in parentheses are percent differences from baseline values:

$$\text{Percent Diff.} = \frac{\text{(Average of before and after baselines) - Device}}{\text{(Average baseline)}} \text{ rounded to nearest percent}$$

UNIVERSITY OF MICHIGAN ENGINE DYNAMOMETER TESTS

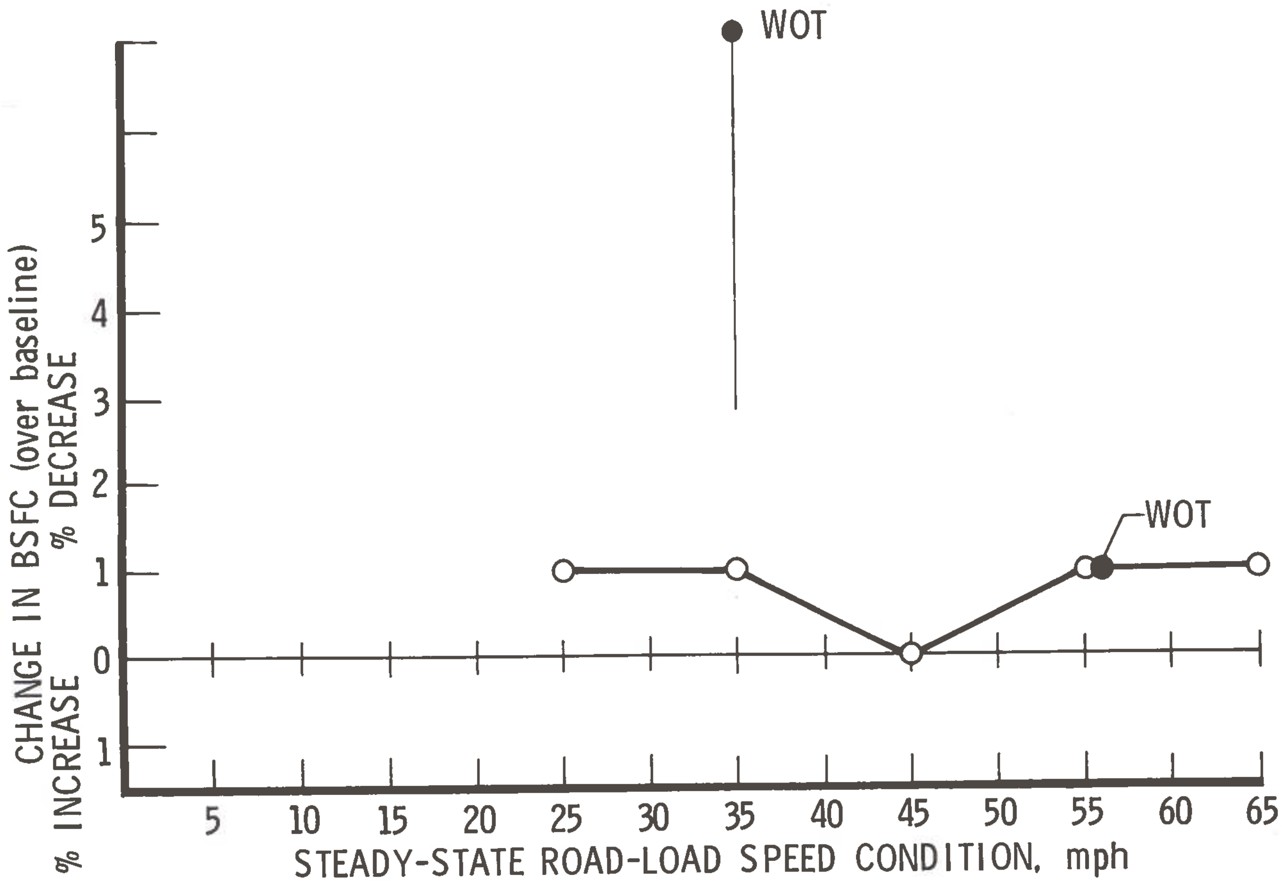


FIGURE 4-9. MSD-2 IGNITION SYSTEM TEST RESULTS — 2-V CONFIGURATION

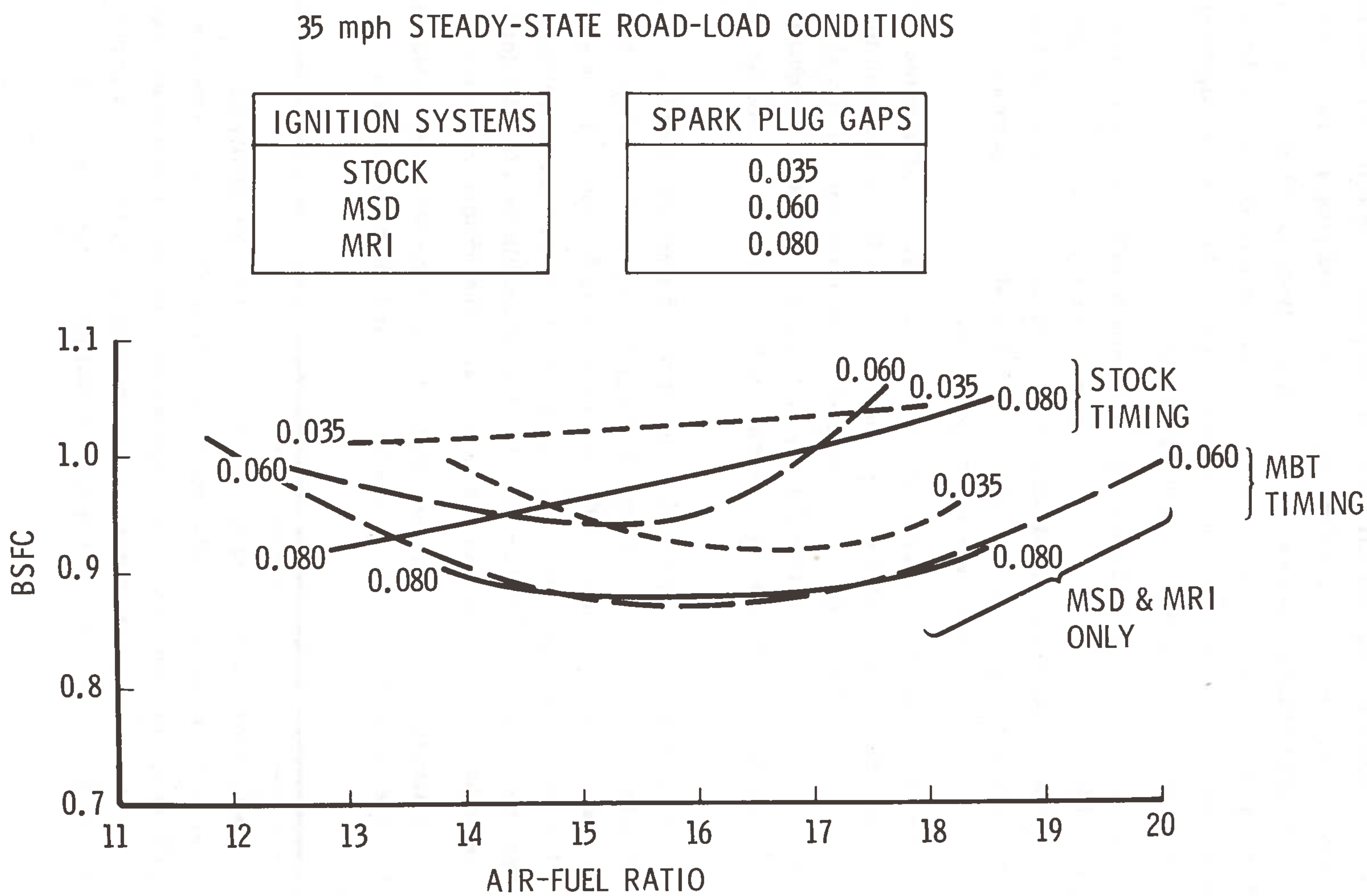


FIGURE 4-10. AIR-FUEL RATIO AND PLUG GAP EFFECTS

With stock timing, for all practical purposes, the effect of plug gap was also small. At the leaner air-fuel ratios, the 0.080 plug gap had some benefit. With MBT timing, increasing the plug gap from 0.035 to 0.060-0.080 resulted in significant decreases in BSFC. At very lean mixtures, in the 17 to 20 range, the high energy ignition systems (MSD and MRI) were improved over the stock ignition system with 0.060 plug gap.

On an overall basis, advancing the timing to MBT and increasing plug gap to 0.060 resulted in a 20 percent improvement in BSFC. Although the stock ignition system performed adequately at these steady-state test conditions, the higher energy ignition system would probably be required to assure acceptable idling and acceleration operation.

These trends are indicative of what has been achieved in some 1975 and 1976 model year cars which have returned to near-MBT timing with the use of catalysts for HC and CO control, and which have incorporated high energy ignition systems. On a retrofit basis, however, this would require substantial distributor modifications, as well as the addition of a new ignition system.

Similar test results were obtained at the 55 mph test condition, as shown in Figure 4-11. There were two major differences. One was a shift in the air-fuel ratios for minimum BSFC from 16-16.5 at 35 mph to 17-18 at 55 mph. The second was that at stock timing, the dashed lines, increasing the plug gap from 0.035 to 0.060 or 0.080 had a noticeable beneficial effect, whereas the impact of such changes was minimal at the 35 mph condition.

Confirmatory chassis dynamometer tests of the MSD were selected to quantify the effects of cold start, acceleration, and idling conditions on fuel economy.

4.4 SCREENING TEST RESULTS SUMMARY

The foregoing screening test results from the University of Michigan test program serve to validate the results of the Phase I analysis and preliminary evaluation task. The selected devices performed much like predicted from the analysis of general spark ignition powered vehicle performance and the characterization of the operational principles of each device.

55 mph STEADY-STATE ROAD-LOAD CONDITIONS

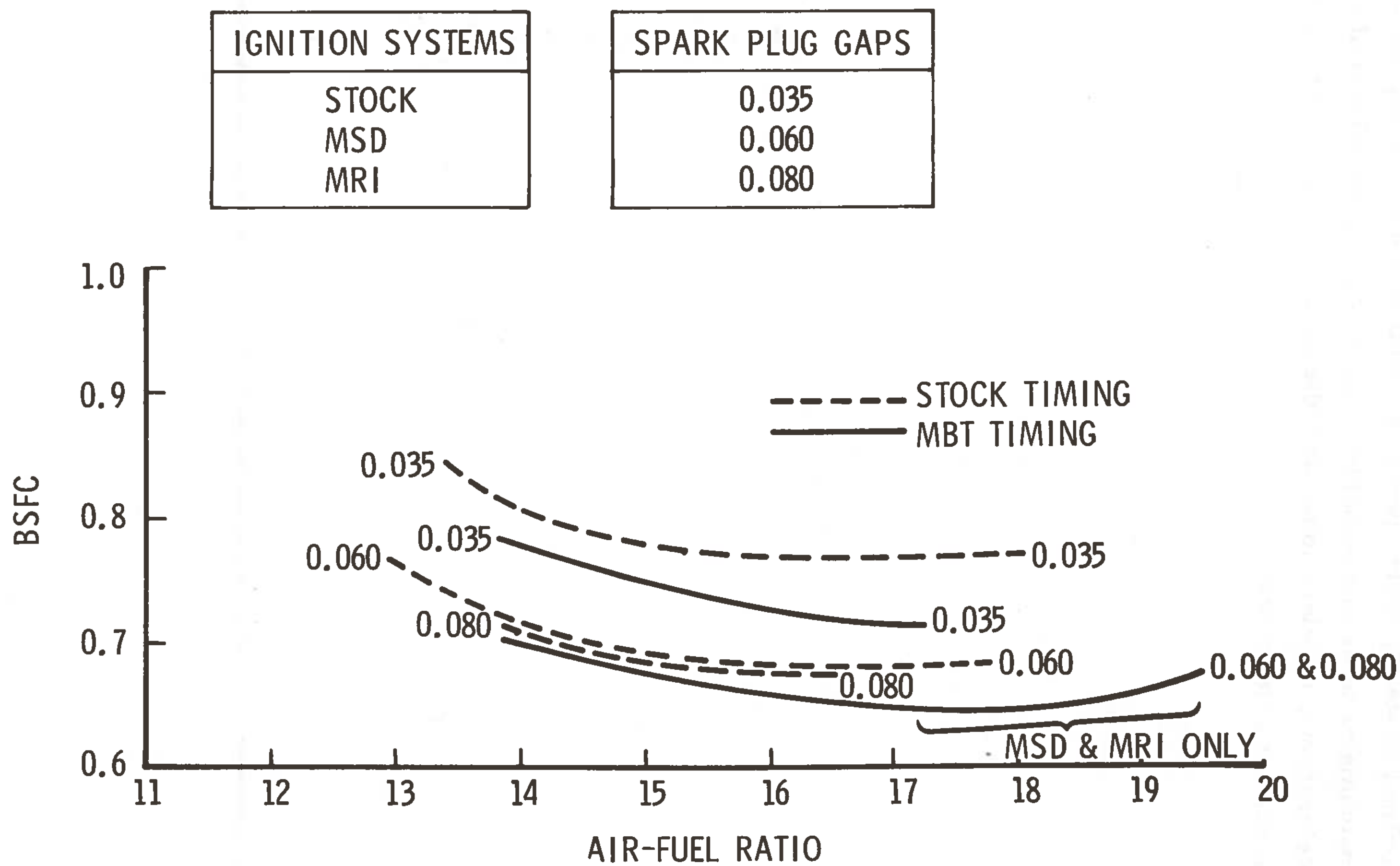


FIGURE 4-11. AIR-FUEL RATIO AND PLUG GAP EFFECTS

These results, however, are limited in their applicability because they are confined to steady-state operating conditions only. Complete vehicle chassis dynamometer tests are required to fully quantify the effects of cold starts, accelerations, decelerations, and idle operation on the overall potential for fuel economy improvement.

SECTION 5

CHASSIS DYNAMOMETER TEST RESULTS

As noted in Section 4, several retrofit devices were tested for fuel economy under steady-state conditions on an engine dynamometer. The purpose of this portion of the program was to subject the more promising of these devices to emissions and fuel economy testing in an actual vehicle operated over the EPA urban and highway driving cycles, and at two steady-state cruise speeds. The types of retrofit devices tested were an inlet manifold, a tuned exhaust system, and a high energy ignition system. These devices were tested in a 1973 Chevrolet Impala.

The goal was to evaluate the effectiveness of these devices under conditions which would be likely to exist if they were retrofitted to in-use vehicles. This meant that stock tune conditions of dwell angle, spark timing, and carburetor adjustment should be maintained. The rationale for this approach was that the great majority of car owners involved would not be hot-rod or performance enthusiasts, and would not give special installation instructions. The mechanics involved (both for the retrofit installation and for subsequent tune-ups) would thus tune to the engine manufacturer's specifications. There was, as noted later, one adjustment made in one of the test configurations, to stock carburetion. This consisted of installing leaner main fuel jets to investigate the effect of leaner air-fuel ratio.

It is important to note that these stock conditions are not necessarily optimum for a particular retrofit device in terms of performance, fuel economy, or driveability. Changing the basic engine tune conditions would represent tampering with the emission control system, however, and would be expected to cause a significant increase in emissions. Also, one could possibly obtain more benefit from the retrofit devices by using an engineering test vehicle which was in ideal maintenance condition throughout the power-train. This would not represent typical in-use conditions, however.

All of the above factors must be taken into account when comparing the test data of this report to specific manufacturers' claims.

5.1 TEST PLAN

The device configurations tested were:

a. Edelbrock High Performance Intake Manifold (Edelbrock Equipment Company, El Segundo, Calif.)

b. Hooker Tuned Exhaust Headers (Hooker Industries, Ontario, Calif.)

c. Edelbrock Intake Manifold plus Hooker Tuned Exhaust Headers

d. MSD-2 Multiple Spark Discharge Ignition System (Autotronic Controls Corporation, El Paso, Texas)

The test series for each configuration (plus the baseline, stock configuration) consisted of two replicate tests in the following sequence: 1975 FTP, EPA HWFET, and steady-state fuel economy and emissions tests at 35 and 55 mph. The test plan is summarized in Table 5-1.

5.2 TEST CONDITIONS

5.2.1 General

The FTP tests were performed in accordance with Federal Register, Vol. 38, No. 124, June 28, 1973 (as amended), paragraphs 85.075-11 through 85.075-26. The HWFET were performed in accordance with Federal Register, Vol. 39, No. 200, October 15, 1974, pages 36893 through 36898. The steady-state tests were performed using the same test conditions and computation procedures as for the FTP and the HWFET.

Testing was performed by Olson Laboratories, Inc., at Livonia, Michigan, and was monitored closely by personnel from The Aerospace Corporation.

5.2.2 Test Vehicle

A 1973 Chevrolet Impala was procured for these tests by the testing laboratory, by purchase from a car dealer. This vehicle was equipped with a stock 350 CID engine, 2-barrel carburetor, automatic transmission, 2.73 rear axle ratio, and G78-15 tires. This was the same type of engine as was used in the preceding engine dynamometer test phase (Section 4). Moreover, the simulated road-load horsepower used in the engine stand work was based on a 1973 Impala with these same drive train parameters.

TABLE 5-1. CHASSIS DYNAMOMETER TEST PROGRAM FOR RETROFIT FUEL ECONOMY DEVICES

Test Series No.*	Device or Configuration
1	Stock Configuration
2	Edelbrock Intake Manifold
3	Edelbrock Intake Manifold plus Hooker Exhaust Header
4	Hooker Exhaust Header
5	Stock Configuration
6	MSD-2 Ignition System, stock fuel jets
7	MSD-2 Ignition System, leaner fuel jets
8	Stock Configuration

*TEST SERIES

Replicate 1	1975 Federal Test Procedure (FTP) EPA Highway Fuel Economy (HWFET) Steady-state Cruise: 35 and 55 mph
Replicate 2	FTP HWFET Steady-state Cruise: 35 and 55 mph

All tests were performed at dynamometer settings of 4500 lb inertia weight and 14.0 hp at 50 mph.

Prior to initiating the tests, the engine tune parameters of timing, dwell, idle rpm, and idle CO and HC were adjusted to manufacturer's specifications. These tune parameters were checked after each test. Minor adjustments to the carburetor idle circuit were made several times during the program to keep the idle parameters within specifications. The rear (dynamometer) tires were new Firestone "Deluxe Champion" belted bias tubeless. They had 2 polyester and 2 fiberglass tread plies, and 2 polyester body plies. They were inflated to the usual test pressure of 45 psi.

At the start of testing, this car had approximately 34,000 miles on the odometer. No information is available concerning its prior use and maintenance history.

5.3 RETROFIT TEST COMPONENTS

This section summarizes the key features or test arrangement of each device. These components were all obtained from the University of Michigan Automotive Laboratory. This laboratory had recently concluded the engine dynamometer tests referred to previously. They in turn had received the components through The Aerospace Corporation, who had purchased or otherwise procured all the retrofit devices tested in that earlier task.

5.3.1 Edelbrock Intake Manifold

The installation of this device was straightforward. The stock EGR port, which is internal to the block and passes up through the inlet manifold, was easily accommodated by means of an adaptor plate. This adaptor plate had been previously procured from the device manufacturer, and had been used in the engine stand tests.

A top view of this manifold is shown in Figure 5-1. Directly aft of the carburetor mounting plate can be seen the internal EGR ports. The stock EGR valve was mounted here. Figure 5-2 is a photograph of the bottom of the manifold. In both of these figures, the front of the engine block corresponds to the left side of the photo. The EGR pickup occurs at the two opposite ports at the outer center of the manifold. The exhaust gases are then

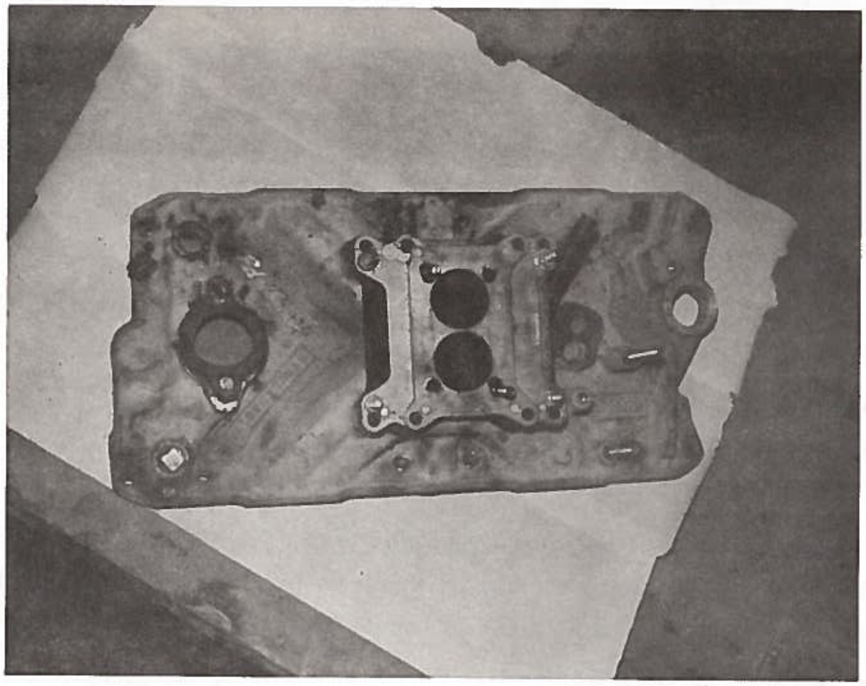


FIGURE 5-1. EDELBROCK STREETMASTER INTAKE MANIFOLD - TOP VIEW

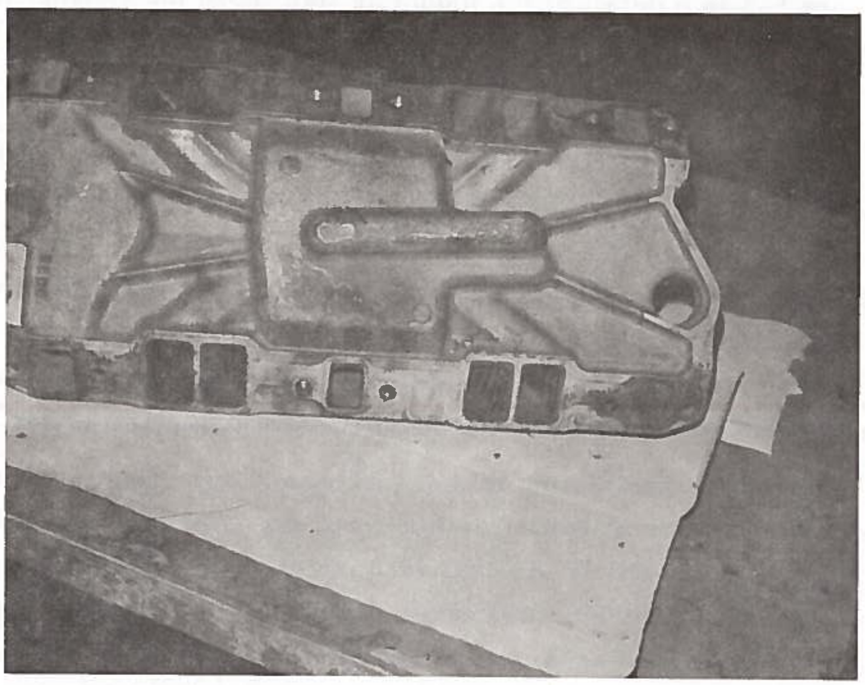


FIGURE 5-2. EDELBROCK STREETMASTER INTAKE MANIFOLD - BOTTOM VIEW

internally ducted to the EGR valve ports shown in Figure 5-1, and thence into the plenum underneath the carburetor, where they are mixed with the air-fuel stream from the carburetor.

5.3.2 Hooker Tuned Exhaust Headers

The as-received headers which had been used in the engine stand tests could not be installed on the vehicle because of interference with the frame and certain components in the engine compartment. The headers were shipped back to the manufacturer, who cut and rewelded them as required to fit, and also welded on bosses to accept the air injection lines.

Upon receipt of the reworked headers, the testing laboratory took the vehicle to a muffler shop for installation of the headers plus a special "Y" exhaust section to connect the two headers to the single vehicle exhaust pipe. The installation required removal of the starter motor.

These headers are shown in Figures 5-3, 5-4, and 5-5. The first photo shows the headers and the "Y" section which was connected to the muffler. Figure 5-4 shows the tube bundle arrangement used for each exhaust bank. Figure 5-5 is a detail of the mounting flanges to the exhaust manifolds, and of the air injection ports.

5.3.3 MSD-2 Ignition System

This component was installed readily into the vehicle ignition system. The MSD-2 unit is shown in Figure 5-6 mounted in the engine compartment, against the left fender wall. The new wiring involved is shown in this photo and in Figure 5-7. The spark plug gap was left at the stock setting of 0.035 in all the tests on the MSD-2 device. This was done after a discussion with the device manufacturer, who stated that their recommendation which accompanied each device kit was that no change in plug gap was required.

One reason for testing this device was to investigate its potential for permitting operation at leaner air-fuel ratios. The device was first tested at the standard vehicle air-fuel ratio, with no change to the carburetor. After this test, the carburetor was taken to the University of Michigan Automotive Laboratory for checkout on the same engine stand used in the related engine dynamometer test program. This stand was equipped to make accurate

FIGURE 5-3. HOOKER TUNED EXHAUST HEADERS WITH "Y" SECTION

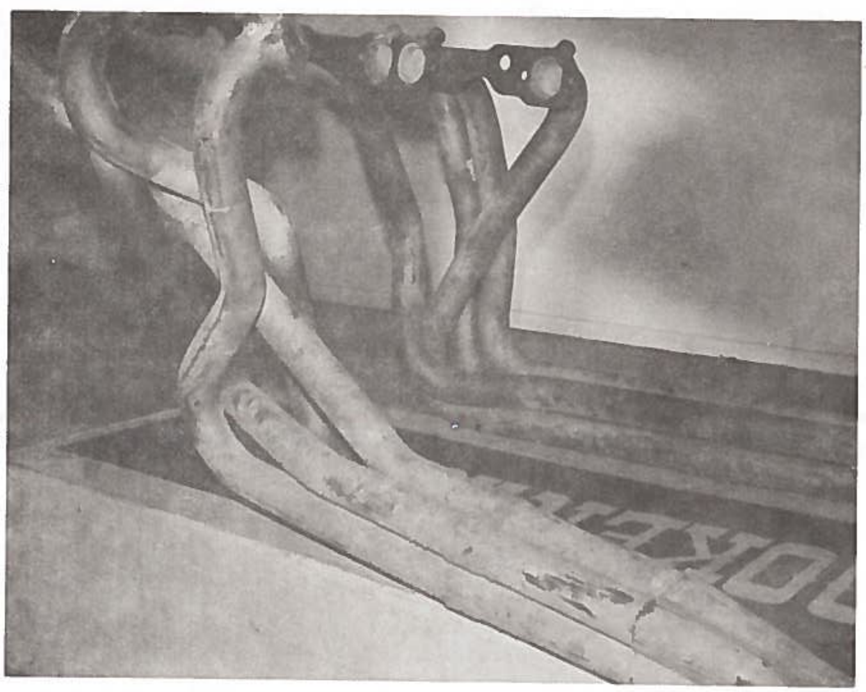


FIGURE 5-4. HOOKER TUNED EXHAUST HEADERS-TUBE BUNDLE ARRANGEMENT

FIGURE 5-5. HOOKER TUNED EXHAUST HEADERS - EXHAUST MANIFOLD MOUNTING FLANGES

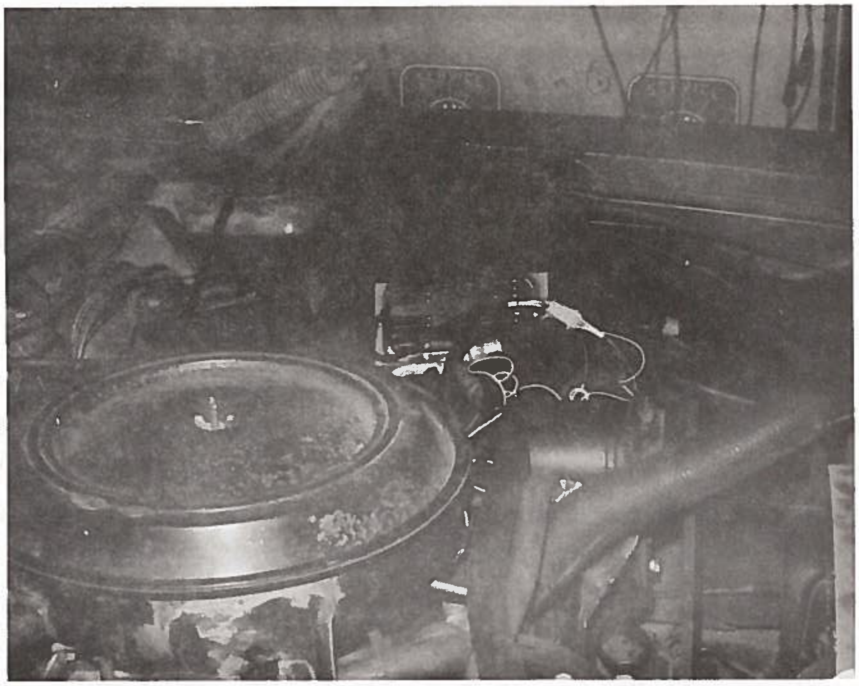


FIGURE 5-6. MSD-2 DEVICE-MOUNTING ARRANGEMENT

FIGURE 5-7. MSD-2 DEVICE - WIRING ARRANGEMENT

air and fuel flow rate measurements. The air-fuel ratio of this carburetor with the stock 0.050-inch main fuel jets was measured by the Automotive Lab to be 14.9 at 55 mph road load, and 13.5 at 35 mph road load. Based on the earlier engine tests with the MSD and other ignition systems, a nominal air-fuel ratio of 17.5 at 55 mph road-load cruise conditions was selected as an appropriate test condition for the vehicle.

The Automotive Lab had a set of matched pairs of jets in the sizes 0.048, 0.046, 0.044, and 0.042. The 0.044 jets were found to provide an air-fuel ratio of 17.6 at 55 mph road load (14.6 at 35 mph road load). The carburetor was then returned to the testing laboratory and installed on the vehicle. With this modified carburetor, the manufacturer's idle specifications no longer applied, so the carburetor idle adjustment was performed by the lean-roll method. The car had a major driveability problem with this configuration, however. There was no problem at idle or at steady-state cruising, but the acceleration was very poor. In particular, it was found during the LA-4 preconditioning cycle that the car could not follow the trace; it stalled, backfired, and could not make the accelerations.

The testing laboratory replaced the 0.044 jets with the next larger size (0.046). The car had basically the same driveability problem as before; it was slightly improved, but still unacceptable for the FTP. The next size larger jets (0.048) were then installed. The vehicle still had a noticeable decrease in throttle response compared with the stock configuration, but it could follow the Federal Driving Cycle. The test plan was therefore continued, using the 0.048 jets. The car stalled one or more times in the first hill of the cold 505 in each replicate, and could not make the acceleration, but it followed the trace for all the rest of each FTP. These were valid tests, since the car was operated WOT during the acceleration of the first hill of each cold start. After these tests were finished, the 0.048 jets were replaced by the stock 0.050 jets, the MSD-2 device was removed, and the stock ignition system reconnected, and two final replicates of the stock, baseline configuration were performed.

At the completion of the test plan, the vehicle carburetor was taken back to the University of Michigan Automotive Lab, where the 0.048 jets were re-installed and the air-fuel ratio measured.

In addition to the air-fuel measurements performed by the University of Michigan Automotive Lab, samples of undiluted exhaust were collected and analyzed by the vehicle testing lab at steady-state cruise speeds of 35 and 55 mph. The air-fuel ratio was computed from the exhaust composition.

5.4 RESULTS

5.4.1 Emissions and Fuel Economy

The complete test results are given in the computer printouts of Appendix A. Abstracted results for fuel economy and composite FTP emissions are shown in Table 5-2. The latter table shows the value for each replic te, in the sequence in which the tests were performed. It also gives the average value for each configuration, and the percent difference between this average value and the average value for the six baseline replicates. Due to test variability, these percent differences do not give sufficient insight into the statistical significance of the results. Conventional t tests for significance were performed for each test condition, including the individual bags (test phases) of the FTP. Table A-2 gives a tabulation of the basic statistics, while Table 5-3 presents the abstracted results of the significance tests. For each test device, the results of three different statistical tests are shown. Column A is the 95 percent confidence level test of the hypothesis that the two populations (baseline and test device) have the same mean. Those cases in which this hypothesis was rejected are shown by a check mark if the significance was favorable (fuel economy higher or emissions lower) or by a cross if the significance was undesirable (fuel economy lower, or emissions higher). There are only nine cases which are statistically significant, none of them involving fuel economy. Four of these pertain to the higher FTP NO_x emissions obtained with the tuned exhaust headers. These results are of interest, but it must be recalled that any statistics based on a sample size of two have an inherently high variability; consequently, the measured difference must become relatively large in order for statistical significance to be observed. This factor tends to conceal certain data trends which are of considerable interest. In order to depict more of these trends, column B of Table 5-3 presents the same test as column A, but at the 90 percent confidence level, rather than 95 percent. It is seen that six additional cases are brought to attention. In a further effort to depict the basic data trends in a

TABLE 5-2. SUMMARY OF CHASSIS DYNAMOMETER TEST RESULTS

Configuration	Composite FTP				HWFET mpg	Steady-State, mpg	
	Gram/Mile			mpg		35 mph	55 mph
	HC	CO	NO_x				
Baseline	2.80	48.96	2.83	10.58	16.68	20.12	17.33
Baseline	2.49	26.24	3.21	11.91	16.47	18.25	16.28
Edelbrock Manifold	1.76	29.40	2.67	10.41	17.50	19.66	17.51
Edelbrock Manifold	1.98	24.74	3.36	10.97	17.92	19.29	17.72
(Average)	(1.87)	(27.07)	(3.02)	(10.69)	(17.71)	(19.47)	(17.62)
(Percent difference between average and average of six baselines)	(-16.5)	(-1.9)	(+20.3)	(-7.1)	(+2.8)	(+1.6)	(+1.6)
Edelbrock Manifold plus Hooker Headers	2.31	27.93	2.64	10.83	16.10	18.90	17.34
Edelbrock Manifold plus Hooker Headers	2.09	23.74	2.56	11.17	17.28	18.34	17.57
(Average)	(2.20)	(25.83)	(2.60)	(11.00)	(16.69)	(18.62)	(17.46)
(Percent difference between average and average of six baselines)	(-1.8)	(-6.4)	(+3.6)	(-4.4)	(-3.1)	(-2.8)	(+0.7)
Hooker Headers	1.97	35.47	4.33	11.19	16.61	18.46	19.04
Hooker Headers	1.77	24.92	4.02	12.46	17.87	18.89	17.80
(Average)	(1.87)	(30.19)	(4.18)	(11.82)	(17.24)	(18.67)	(18.42)
(Percent difference between average and average of six baselines)	(-16.5)	(+9.4)	(+66.5)	(+2.7)	(+0.1)	(-2.6)	(+6.2)
Baseline	1.72	15.88	2.19	12.08	17.85	19.43	18.00
Baseline	1.63	14.84	2.21	12.23	18.00	19.48	18.03

TABLE 5-2. SUMMARY OF CHASSIS DYNAMOMETER TEST RESULTS (Continued)

Configuration	Composite FTP				HWFET mpg	Steady-State, mpg	
	Gram/Mile			mpg		35 mph	55 mph
	HC	CO	NO_x				
MSD, stock (0.050) Carburetor Jets	1.20	19.72	2.61	11.01	17.07	19.07	17.48
MSD, stock (0.050) Carburetor Jets	1.35	19.57	2.65	10.62	17.28	18.76	17.26
(Average)	(1.27)	(19.64)	(2.63)	(10.81)	(17.17)	(18.91)	(17.37)
(Percent difference between average and average of six baselines)	(-43.3)	(-28.8)	(+4.8)	(-6.1)	(-0.3)	(-1.3)	(+0.2)
MSD, lean (0.048) Carburetor Jets	1.51	15.46	2.41	11.27	17.12	18.39	16.84
MSD, lean (0.048) Carburetor Jets	1.45	16.08	2.36	11.28	17.35	18.66	17.01
(Average)	(1.48)	(15.77)	(2.38)	(11.27)	(17.25)	(18.52)	(16.92)
(Percent difference between average and average of six baselines)	(-33.9)	(-42.8)	(-5.2)	(-2.1)	(+0.2)	(-3.3)	(-2.4)
Baseline	2.99	44.26	2.14	10.66	16.87	18.58	17.20
Baseline	1.83	15.35	2.48	11.58	17.48	19.09	17.19
(Average of Six Baselines)	(2.24)	(27.59)	(2.51)	(11.51)	(17.22)	(19.16)	(17.34)
(1973 Certification Values, Corrected to 1975 FTP)	(2.4)	(14.0	(2.5)	(12.5)			

TABLE 5-3. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES – STATISTICAL ANALYSIS

		EDELBROCK MANIFOLD			EDELBROK MANIFOLD + HOOKER HEADERS			HOOKER HEADERS			MSD-2 STD AIR-FUEL			MSD-2 LEANER AIR-FUEL		
		A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
FTP																
FE	1			X									X			
	2															
	3															
	COMP			(X)												
HC	1												√			
	2											√	√		√	√
	3															
	COMP											√	(√)			(√)
CO	1															
	2															
	3															
	COMP															
NO_x	1							X	X	X						
	2	X	X	X				X	X	X						
	3							X	X	X						
	COMP			(X)				(X)	(X)	(X)						
HWFET																
FE																
HC												√	√			√
CO																
NO_x										X	X	X	X			
35 MPH SS																
FE																
HC							X		X	X			√			√
CO										X						
NO_x									X	X						X
55 MPH SS																
FE										(√)						
HC																
CO		X	X	X	X	X	X	X	X	X						√
NO_x																

LEGEND

COLUMNS A & B:
REJECT HYPOTHESIS THAT TEST CONFIGURATION AND BASELINE POPULATION HAVE THE SAME MEAN LEVEL OF SIGNIFICANCE (α) IS:

COLUMN A	0.05
COLUMN B	0.1

COLUMN C:
MEAN OF 2 REPLICATES OF TEST CONFIGURATION FALLS OUTSIDE OF 95% CONFIDENCE INTERVAL FOR MEAN OF BASELINE POPULATION

"X" DENOTES UNFAVORABLE DIFFERENCE (FE LOWER OR EMISSIONS HIGHER)

"√" DENOTES FAVORABLE DIFFERENCE (FE HIGHER OR EMISSIONS LOWER)

CASES OF DIFFERENCE IN FTP COMPOSITE RESULTS, AND ALL FE RESULTS FROM HWFET AND STEADY STATES, ARE CIRCLED highly visible form, column C presents those cases in which the mean of the two replicates for the test device falls outside the 95 percent confidence limits for the baseline population mean determined from the six baseline replicates. This procedure draws attention to 21 cases which are not picked up by column A.

The highlights of these tables are presented in the following discussion. It must be emphasized that these comments apply just to the data base of these tests. In view of the rather extreme variability which is sometimes encountered in chassis dynamometer testing, other factors must be taken into account before one can attempt to draw wide-ranging conclusions.

It is seen from Table 5-2 that the Edelbrock inlet manifold showed a slight increase in average fuel economy for the HWFET and the steady-state speed conditions, but these are not statistically significant. It showed an average 7.1 percent decrease in composite FTP fuel economy, and this is significant for column C of Table 5-3. It also showed higher NO_x for the composite FTP, due mostly to the contribution of the cold stabilized phase. The Hooker headers were the only device which showed an increase in fuel economy at any test condition in Table 5-3; this occurred at the 55 mph steady-state road-load condition (6.2 percent higher than average baseline). The headers produced higher NO_x in all test phases except the 55 mph steady state. It is interesting to note that the combination of the Edelbrock manifold and the Hooker headers did not show a significant increase in NO_x over the stabilized bag of the FTP, while each device tested separately did show a significant increase. Each of these two devices, individually and in combination, showed an increase in CO emission at the 55 mph steady state, by a factor of 2 to 3.

Although the MSD-2 device did not show any significant increase in fuel economy (the average values were in general slightly less than the average baseline values), it is of interest that this device showed a column C decrease in HC emissions in all tests except for the 55 mph steady state. With the stock carburetor fuel jets, the MSD-2 device showed higher NO_x in the HWFET; with the next leaner size jets, this device showed higher NO_x in the 35 mph steady-state condition. The latter case is not important, since the NO_x level in the 35 mph steady state is the lowest of any of the test phases (0.76 gr/mile average for the six baselines). The increased NO_x emission in the HWFET is of more importance, since the average baseline NO_x in gr/mile in the HWFET is comparable to the gr/mile NO_x generated in the FTP.

5.4.2 Air-Fuel Ratio Variation with MSD-2 Ignition System

Table 5-4 summarizes the air-fuel measurements performed during these tests. The sequence of events which led to these test conditions was described in Section 5.3.3. The two sets of measurements (engine stand vs. vehicle test) at 55 mph steady-state road-load and 0.048-in. carburetor jets, agree closely. For the other test conditions, however, the agreement is poor, with the vehicle tests showing the higher air-fuel by 1.4 to 1.7 air-fuel units. This discrepancy cannot be readily resolved. On the one hand, the engine stand measurements with the stock carburetor jets gave results close to what one would expect for a 1973 vehicle. Also, the increase in air-fuel measured on the engine stand with the 0.044 jets looks reasonable. The air-fuel values measured on the engine stand with 0.048 jets, however, are surprisingly close to those measured with the 0.044. The engine stand air-fuel measurements with the 0.050 and 0.048 jets occurred at the beginning and the end, respectively, of the vehicle chassis dynamometer tests with the MSD-2 device. In the time interval between the two measurements, it was necessary for the testing laboratory to partially dismantle the carburetor, because of a flooding problem. Inspection revealed some dirt in the carburetor which may have jammed the float. The carburetor was cleaned, after which it performed normally.

The computation of air-fuel ratio for the vehicle tests utilized a complete mass balance which took into account the concentration of CO_2, CO, HC, NO_x, and H_2O in both the exhaust sample and in the background air. It involved a computer solution of eleven simultaneous equations. The HC analyzer in the analytical bench used for these measurements was not operative, but this could account for only a very small (negligible) fraction of the observed discrepancy.

TABLE 5-4. AIR-FUEL RATIO MEASUREMENTS

Carburetor Jet Size, inches	Test Location and Conditions	Air-fuel Ratio Determined by	Measured Air-fuel Ratio at Steady-state Road-load Speeds of	
			35 mph	55 mph
0.050 (stock)	Vehicle carburetor installed on engine dyno stand at University of Michigan Automotive Lab	Measurement of air and fuel flow rates	13.5	14.9
0.044	↓	↓	14.6	17.6
0.048	↓	↓	14.4	17.2
0.048	Carburetor on test vehicle, chassis dyno test at Olson Labs, Livonia	Measurement of tailpipe concentrations (air injection pump disconnected); air-fuel ratio computed from reaction stoichiometry	15.8	17.4
0.050	↓	↓	15.0	16.5
0.050	↓	↓	15.1	16.7

5.4.3 Discussion of Results

The results of these chassis dynamometer tests provide the information which is required to supplement the evaluations performed at earlier stages of this program. They supply the key input concerning the effects of selected retrofit devices on a vehicle operating over a wide, but controlled, range of driving conditions. In addition, they help answer the important questions concerning the effect of these devices on vehicle emissions. These results show that the FTP tends to be a "leveler" of fuel economy retrofit devices. By this it is meant that the FTP, with its demanding test conditions of cold start followed quickly by major accelerations, and its high frequency of idling in between relatively abrupt accelerations and decelerations, cause the fuel consumption to be governed primarily by such fundamental factors as engine displacement, vehicle inertia, and basic carburetion. The HWFET is also affected by these same factors, but to a lesser extent than the FTP.

The engine dynamometer tests described in Section 4 showed that the Edelbrock inlet manifold had a large beneficial effect at the lower steady-state speeds. These effects were apparently overridden in the FTP by the above mentioned factors. These low speeds do not occur in the HWFET, so it is not surprising that the manifold did not show a significant improvement in this test. The manifold showed a slight, but not statistically significant, increase in the average fuel economy in the vehicle test at 35 mph steady state; this contrasts rather sharply with the 15 percent decrease in BSFC shown in the engine stand test at 35 mph road load.

The tuned exhaust headers showed an improvement in fuel economy in the vehicle test at 55 mph steady state. The improvement was greater than that shown in the engine stand test at the same conditions. This result was expected, as this test condition represents near-optimum conditions for these tuned headers. This improvement occurred at the expense of significant increase in NO_x emissions, however. It is somewhat surprising that the headers did not reveal an improvement in vehicle fuel economy on the HWFET. The combination on the vehicle of the inlet manifold plus the headers did not reveal any improvement.

No significant fuel economy increase was predicted for the MSD-2 device based on the engine stand tests, and none was found in the vehicle tests. A key finding here was that this device, by itself, did not permit operation in the vehicle at significantly increased air-fuel ratio, without an objectionable degradation of driveability. The device manufacturers do not make such a claim, but this question was of interest because of the engine dynamometer tests at leaner air-fuel ratio. On the other hand, this ignition system shows an interesting trend of reduced HC emissions, indicating that it accomplished one of its main purposes; namely, helping to promote improved combustion of residual cylinder gases.

In conclusion, these vehicle chassis dynamometer tests do not show any basis, with respect to fuel economy improvement, for recommending wide-scale implementation of any of the retrofit devices tested herein. It must be stressed again that this conclusion applies within the test constraints as described in the introduction to this section. The test results indicate that caution is in order in regard to the use of tuned exhaust headers because of the possibility of increased NO_x emissions. Certain high energy and/or multiple spark discharge systems, such as the MSD-2 device, may provide a decrease in HC emissions.

SECTION 6

ULTRASONIC FUEL INDUCTION SYSTEM TESTS

6.1 DEVICE DESCRIPTION

The Ultrasonic Fuel Induction System is a computer-regulated fuel delivery system, with ultrasonic atomization of the fuel just prior to induction into the intake manifold. The intended function of the device is to control fuel flow so as to maintain a fixed, lean air-fuel ratio over a range of vehicle operating conditions, and provide a controlled degree of fuel enrichment for acceleration modes. The device was invented by A. K. Thatcher and E. McCarter of Orlando, Florida. Figure 6-1 depicts the essential features of this system.

Three main functions are involved in its operation. First, an on-board electronic computer adjusts the pre-programmed fuel flow rates in accordance with input sensing of engine rpm, manifold pressure, and engine compartment temperature. Secondly, a metering pump delivers the fuel to two injector nozzles which direct the fuel onto the active surface of the ultrasonic unit. The latter unit, the third main component, acts to break up the fuel stream into a fine mist which is mixed with intake air. In the configuration tested, the air flow was regulated by a slide plate which was linkage-controlled by the foot throttle. Additionally, some auxiliary tests were performed in which the slide plate mechanism was replaced by the conventional butterfly throttle valve of the stock carburetor (mounted on top of the ultrasonic fuel induction unit). In this arrangement, the carburetor throttle linkage was in stock configuration, and there was no fuel connection to the carburetor.

The device had been installed in a 1972 Plymouth Duster and driven for more than 1500 miles prior to being driven from Florida to Michigan by one of the inventors, for the purpose of participating in these tests. The fuel system had been described in the popular automotive press prior to these tests. Mileage and emission improvement claims were made therein, but their basis did not appear to be sufficiently established to permit an engineering assessment of the device's performance.

- TYPE
  - COMPUTER-CONTROLLED ACOUSTIC ATOMIZER
- COMPONENTS
  - ATOMIZER
  - COMPUTER
  - FUEL METERING PUMP
- APPROACH
  - DELIVER A FIXED, LEAN AIR-FUEL RATIO OVER A RANGE OF OPERATING CONDITIONS
- CLAIMS
  - 25-30% FUEL ECONOMY IMPROVEMENT
  - MEET 1975 EMISSION STANDARDS
- DEVELOPMENT STATUS
  - RESEARCH PROTOTYPE
    - ONE TEST UNIT PRESENTLY ON A CAR
- COST FACTORS
  - INVENTORS ESTIMATE MANUFACTURING COST AT ~$50

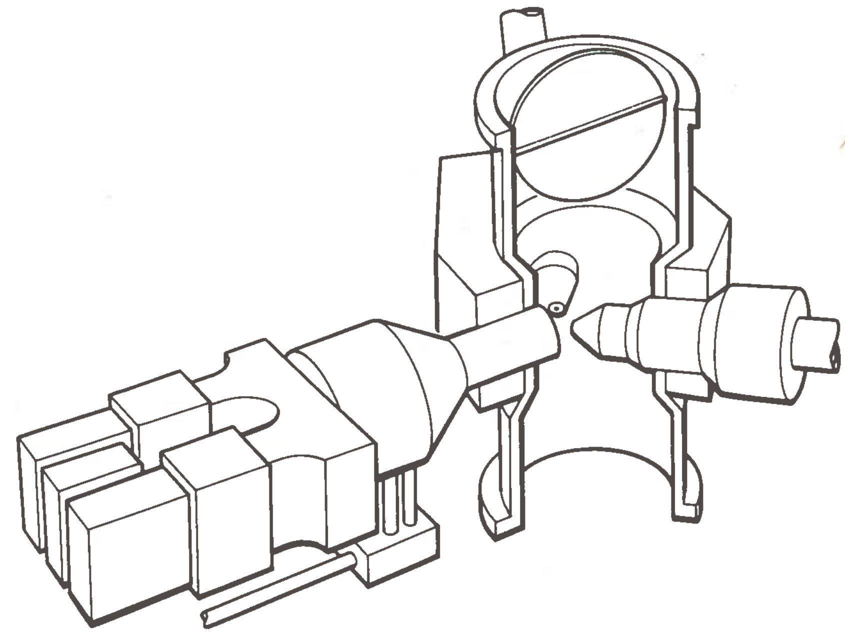


FIGURE 6-1. ULTRASONIC FUEL SYSTEM- A. K. THATCHER AND E. MCCARTER

The device was installed in a 1972 Plymouth Duster with 225 CID slant-six engine, with automatic transmission. The main housing unit for the fuel induction device contained the fuel injectors, ultrasonic vibrator, and slide plate mechanism. The unit was bolted to the manifold inlet at the position formerly occupied by the stock one-barrel carburetor. An air inlet horn, to which the air filter was clamped, was attached directly above the unit. The stock fuel pump was left in place, but was isolated from the fuel system.

The engine tune parameters were adjusted to manufacturer's specifications at the start of these tests. The tune parameters were checked several times during the test plan.

A Delta Mark Ten capacitive discharge system had been installed on the vehicle, and had been in operation during all the development effort. The car was equipped with a standard Chrysler air conditioning system. The tires were all Goodyear "Power Cushion" 6.95 x 104, 2-ply, with polyester cord. Both rear tires were in rather worn condition. The vehicle odometer read approximately 25,000 miles at the time of these tests.

6.2 TEST PLAN

The test plan consisted of two replicate test series for each of three configurations. The first configuration consisted of the fully operational ultrasonic system. In the second, the ultrasonic vibrator was disconnected. The reason for this was to distinguish between the effects of air-fuel ratio control and fuel atomization for different operating conditions, such as the cold and hot start portions of the FTP. The inventors had previously suggested the possibility of operating without the ultrasound after the engine became thoroughly warmed up.

The third test configuration comprised complete deactivation of the fuel induction system, and replacement with the stock carburetor. In this configuration, the carburetor was adjusted according to the vehicle manufacturer's recommended procedure, with no other changes to any vehicle or engine parameter.

Each configuration was tested twice by the 1975 FTP, the EPA HWFET, and at two steady-state speeds. The testing laboratory and the test details are identical to those described in Section 5. One of the inventors of the device was present for all tests in which the Ultrasonic Fuel Induction System was in operation.

6.3 RESULTS

Detailed results are given in Table 6-1. Abstracted fuel economy and emission results are given in Tables 6-2 and 6-3, respectively. These latter two tables give the average value of the two replicates at each test condition.

With the ultrasonic device fully operational, the vehicle fuel economy was approximately 3 percent poorer than the stock vehicle on the FTP, and approximately 2 percent better on the Highway Driving Cycle. It had a 6 percent improvement at 35 mph, and 3 percent improvement at 55 mph. With the ultrasound disconnected, the results were not greatly different, except at the 55 mph conditions.

It is likely that the projected fuel economy claims for this device were in error because of the condition of the stock carburetor to which the device was compared. When installed for baseline tests, the stock carburetor was flooding badly and could not be adjusted to give factory settings at idle conditions. Therefore, a new stock carburetor was used for the baseline test data shown in the figure.

With the ultrasonic device operational, there were significant reductions in HC and CO. These results would be consistent with a more uniform fuel-air mixture promoting a higher flame temperature, but without a sufficient increase in air-fuel ratio to bring about a reduction in NO_x. The device inventor found it necessary in these tests to adjust the on-board computer setting to provide a somewhat richer mixture than the prior setting, in order for the car to be able to follow the Federal Driving Cycle.

It should be noted that the small number of tests run does not permit a statistical determination of the relative efficacy of this device. On the basis of the tests made, however, there do not appear to be any significant differences in fuel economy, particularly in view of normal test measurement accuracy limitations.

TABLE 6-1. FINALIZED TEST RESULTS – ULTRASONIC FUEL INDUCTION SYSTEM EMISSIONS AND FUEL ECONOMY TESTING

VEHICLE: 1972 PLYMOUTH DUSTER
ENGINE: 225 CID SLANT 6

TESTS PERFORMED BY: OLSON LABORATORIES, INC., LIVONIA, MICHIGAN
TESTING DATES: 1/27/75 – 2/7/75

TEST NO.	TEST CONFIG.	FEDERAL TEST PROCEDURES: TEST PHASE EMISSIONS, GRAMS: COLD START				COLD STABILIZED				HOT START				COMPOSITE FTP: EMISSIONS, GR/MILE			FUEL MPG	HIGHWAY FUEL ECONOMY: EMISSIONS, GR/MILE			FUEL RATE MPG	STEADY STATE: 35 MPH EMISSIONS, GR/MILE			FUEL MPG	55 MPH EMISSIONS, GR/MILE			FUEL MPG
		HC	CO	NO_x	CO_2	HC	CO	NO_x	CO_2	HC	CO	NO_x	CO_2	HC	CO	NO_x		HC	CO	NO_x		HC	CO	NO_x		HC	CO	NO_x	
1	1	9.30	117.41	20.53	1936.9	5.35	27.83	18.53	2254.7	6.17	73.37	17.80	1724.1	1.72	16.02	5.00	15.48	1.33	9.63	4.26	24.13	0.59	1.83	1.99	29.26	0.77	4.92	4.39	26.09
2	1	10.21	129.24	20.66	1895.9	5.67	26.43	17.99	2198.7	6.71	67.11	18.40	1677.4	1.85	16.03	4.98	15.84	1.20	4.46	3.91	26.52	0.57	1.93	1.63	32.48	0.55	2.81	3.85	27.18
	AVG													1.78	16.02	4.99	15.66				25.32				30.87				26.64
3	2	17.87	254.69	16.91	1719.2	9.49	98.53	16.72	2076.5	8.54	130.22	15.97	1542.9	2.94	37.64	4.41	15.82	1.44	11.45	4.44	25.69	0.95	3.51	2.24	31.50	0.81	4.00	4.95	25.52
4	2	14.41	180.87	18.82	1725.4	8.77	49.03	18.39	2034.6	9.55	102.29	17.62	1566.9	2.72	24.68	4.87	16.54	1.44	7.31	4.69	26.16	0.83	1.92	2.14	30.73	0.88	4.13	5.31	24.32
	AVG													2.83	31.16	4.64	16.18				25.92				31.12				24.92
5	3	8.81	104.39	18.08	1805.1	7.57	28.78	13.43	2028.3	7.49	42.86	17.08	1621.8	2.08	13.08	4.13	16.93	0.98	4.21	3.94	25.04	1.34	2.27	1.19	29.30	0.50	3.44	3.22	26.10
6	3	20.51	440.75	13.72	1686.0	6.38	39.64	14.75	2193.8	6.75	76.42	17.05	1690.2	2.54	36.36	4.05	15.23	0.81	6.18	4.13	24.67	0.87	2.00	1.23	28.90	0.50	4.62	3.48	25.51
	AVG													2.31		4.09	16.08				24.86				29.10				25.80
G-1	4	6.62	83.50	19.60	1881.3	4.14	27.23	18.17	2237.4	25.95	58.81	17.50	1693.1	2.90	12.89	4.88	15.73	0.83	4.65	4.01	24.50	0.55	1.75	1.29	31.20	0.34	2.31	5.13	26.46
THE FOLLOWING TESTS WERE OF A PRELIMINARY NATURE, AND WERE NOT OBSERVED BY THE AEROSPACE CORPORATION. DOCUMENTATION OF THE EXACT TEST CONFIGURATION WAS NOT AVAILABLE IN EVERY CASE.																													
P-1	5	7.66*	67.44*	18.96*	1864.8*	3.80	16.29	15.60	2329.3	5.77	23.91	18.74	1734.3	1.38	7.86	4.59	15.68												
P-2	6																	0.98	3.05	3.45	27.37								
P-3	7																	1.03	2.66	3.00	28.50								
P-4	8																	0.73	5.27	3.75	28.78								

TEST CONFIGURATION

1 ULTRASONIC FUEL INDUCTION DEVICE FULLY OPERATIONAL. R, COMPUTER CONTROL, = 3.25. THIS LATTER QUANTITY AFFECTS THE FUEL ENRICHMENT, HIGHER VALUES OF THIS SETTING TEND TO PRODUCE A RICHER MIXTURE (LOWER AIR-FUEL RATIO) AIR FLOW CONTROL IS VIA A SLIDE PLATE LINKED TO FOOT THROTTLE

2 SAME AS 1, EXCEPT ULTRASOUND DISCONNECTED

3 NEW STOCK CARBURETOR, MOUNTED ON TOP OF THE DEACTIVATED ULTRASONIC DEVICE

4 SAME AS 1, EXCEPT R = 3.5

5 1ST TEST OF DEVICE. CONFIGURATION BELIEVED TO BE THE SAME AS 1, EXCEPT R = 3.0. *NOTE: THIS WAS A SIMULATED COLD START, VEHICLE LEFT OUTSIDE IN APPROXIMATELY 30°F AMBIENT FOR 3-4 HOURS

6 SLIDE PLATE AIR VALVE REMOVED. AIR FLOW CONTROL VIA STOCK FOOT THROTTLE LINKAGE TO STOCK CARBURETOR BUTTERFLY VALVE. CARBURETOR MOUNTED ABOVE FULLY OPERATIONAL ULTRASONIC DEVICE. NO FUEL CONNECTION TO CARBURETOR. R = 3.0

7,8 SAME AS 6, EXCEPT R = 2.5 AND 3.5, RESPECTIVELY

TABLE 6-2. FUEL ECONOMY TEST RESULTS, ULTRASONIC FUEL INDUCTION SYSTEM, 1972 PLYMOUTH DUSTER; 225 CID ENGINE

Configuration	FTP Fuel Economy mpg(3)(4)	Highway Fuel Economy mpg(3)(4)	Steady-State Fuel Economy, mpg(3)(4)	
			35 mph	55 mph
Ultrasonic Device Fully Operational(1)	15.66 (-2.7)	25.32 (+1.8)	30.87 (+6.0)	26.64 (+3.2)
Ultrasonic Device ON; Ultrasound Disconnected	16.18 (+0.6)	25.92 (+4.2)	31.12 (+6.9)	24.92 (-3.4)
New Stock Carburetor; Baseline Case(2)	16.08	24.86	29.10	25.80

(1)Computer control set by A. K. Thatcher for air-fuel ratio in 17.5-18 range.

(2)Standard air/fuel ratio

(3)Numbers in parentheses represent percent change over baseline case.

(4)Average of 2 tests

TABLE 6-3. EMISSION TEST RESULTS, ULTRASONIC FUEL INDUCTION SYSTEM, 1972 PLYMOUTH DUSTER; 225 CID ENGINE

Configuration	FTP Composite Emissions, gr/mile(3)(4)		
	HC	CO	NO_x
Ultrasonic Device Fully Operational(1)	1.78 (-23.0)	16.02 (-35.0)	4.99 (+22.0)
Ultrasonic Device ON; Ultrasound Disconnected	2.83 (+23.0)	31.16 (+26.0)	4.64 (+13.0)
New Stock Carburetor; Baseline Case(2)	2.31	24.72	4.09

(1) Computer control set by A. K. Thatcher for air-fuel ratio in 17.5-18 range.

(2) Standard air/fuel ratio

(3) Numbers in parentheses represent percent change over baseline case.

(4) Average of 2 tests

APPENDIX A

CHASSIS DYNAMOMETER TEST RESULTS

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS

TEST SEQUENCE 1

BASELINE, FIRST REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0005

		HC	CO	NOX	CO2
GRAMS:	COLD	12.79	224.58	11.74	2617.32
	STABILIZED	10.31	177.80	8.58	3149.28
	HOT	9.16	162.88	13.38	2411.09
GRAMS/MILE:	COMPOSITE	2.89	48.96	2.83	753.21

MILES/GALLON: 10.58

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0006

	HC	CO	NOX	CO2
GRAMS:	14.58	281.48	25.01	4959.59
GRAMS/MILE:	1.42	27.48	2.44	484.24

MILES/GALLON: 16.68

STEADY STATE — RUN NUMBER 2B0008

		HC	CO	NOX	CO2
GRAMS:	35MPH	3.27	45.27	2.62	1242.01
	55MPH	2.75	9.40	14.32	1513.09
GRAMS/MILE:	35MPH	1.09	15.09	0.87	414.00
	55MPH	0.92	3.13	4.77	504.36

MILES/GALLON: 35MPH 20.12
55MPH 17.33

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 2

BASELINE, SECOND REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0009

		HC	CO	NOX	CO2
GRAMS:	COLD	12.76	128.24	15.65	2555.24
	STABILIZED	8.61	105.15	8.49	2827.00
	HOT	7.96	64.01	15.60	2271.29
GRAMS/MILE:	COMPOSITE	2.49	26.24	3.21	696.05

MILES/GALLON: 11.91

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0010

	HC	CO	NOX	CO2
GRAMS:	6.10	154.48	23.19	5257.82
GRAMS/MILE:	0.60	15.08	2.26	513.36

MILES/GALLON: 16.47

STEADY STATE — RUN NUMBER 2B0012

		HC	CO	NOX	CO2
GRAMS:	35MPH	1.60	39.20	1.75	1351.60
	55MPH	1.30	18.79	11.03	2465.28
GRAMS/MILE:	35MPH	0.55	13.44	0.60	463.35
	55MPH	0.28	4.10	2.41	537.92

MILES/GALLON: 35MPH 18.25
55MPH 16.28

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 3

EDELBROCK INLET MANIFOLD, FIRST REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0013

		HC	CO	NOX	CO2
GRAMS:	COLD	9.41	154.75	9.55	2758.65
	STABILIZED	6.01	94.40	9.51	3389.90
	HOT	5.49	104.50	11.23	2503.69
GRAMS/MILE:	COMPOSITE	1.76	29.40	2.67	800.43
MILES/GALLON:	10.41				

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0014

	HC	CO	NOX	CO2
GRAMS:	6.14	150.90	22.60	4937.80
GRAMS/MILE:	0.60	14.73	2.21	482.11
MILES/GALLON: 17.50				

STEADY STATE — RUN NUMBER 2B0016

		HC	CO	NOX	CO2
GRAMS:	35MPH	2.18	20.95	1.99	1276.91
	55MPH	1.94	42.13	13.03	2250.56
GRAMS/MILE:	35MPH	0.75	7.18	0.68	437.75
	55MPH	0.42	9.19	2.84	491.07
MILES/GALLON:	35MPH	19.66			
	55MPH	17.51			

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 4

EDELBROCK INLET MANIFOLD, SECOND REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0017

		HC	CO	NOX	CO2
GRAMS:	COLD	11.47	130.83	13.88	2779.75
	STABILIZED	6.69	95.43	10.00	3141.50
	HOT	5.71	59.40	16.20	2445.35
GRAMS/MILE:	COMPOSITE	1.98	24.74	3.36	764.09
MILES/GALLON:	10.97				

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0018

	HC	CO	NOX	CO2
GRAMS:	6.50	100.68	34.15	4893.60
GRAMS/MILE:	0.63	9.83	3.33	477.80
MILES/GALLON: 17.92				

STEADY STATE — RUN NUMBER 2B0019

		HC	CO	NOX	CO2
GRAMS:	35MPH	2.19	18.09	2.16	1038.24
	55MPH	2.05	23.21	15.07	1793.96
GRAMS/MILE:	35MPH	0.94	7.75	0.93	445.03
	55MPH	0.56	6.33	4.11	489.22
MILES/GALLON:	35MPH 19.29				
	55MPH 17.72				

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 5

EDELBROCK MANIFOLD PLUS HOOKER HEADERS, FIRST REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0021

		HC	CO	NOX	CO2
GRAMS:	COLD	10.95	127.27	10.45	2776.57
	STABILIZED	8.53	107.89	7.84	3128.60
	HOT	7.11	82.15	13.10	2526.56
GRAMS/MILE:	COMPOSITE	2.31	27.93	2.64	768.35

MILES/GALLON: 10.83

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0022

	HC	CO	NOX	CO2
GRAMS:	10.28	183.81	29.32	5326.07
GRAMS/MILE:	1.00	17.95	2.86	520.02

MILES/GALLON: 16.10

STEADY STATE — RUN NUMBER 2B0023

		HC	CO	NOX	CO2
GRAMS:	35MPH	2.76	43.55	1.83	1292.79
	55MPH	3.40	71.22	10.41	2222.84
GRAMS/MILE:	35MPH	0.95	14.93	0.63	443.19
	55MPH	0.74	15.54	2.27	485.02

MILES/GALLON: 35MPH 16.90
55MPH 17.34

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 6

EDELBROCK MANIFOLD PLUS HOOKER HEADERS, SECOND REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0025

		HC	CO	NOX	CO2
GRAMS:	COLD	9.08	89.73	11.37	2704.84
	STABILIZED	7.89	104.04	7.38	3083.23
	HOT	6.84	62.20	12.19	2423.79
GRAMS/MILE:	COMPOSITE	2.09	23.74	2.56	750.38

MILES/GALLON: 11.17

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0026

	HC	CO	NOX	CO2
GRAMS:	8.83	110.87	27.18	5058.51
GRAMS/MILE:	0.86	10.82	2.65	493.90

MILES/GALLON: 17.28

STEADY STATE — RUN NUMBER 2B0027

		HC	CO	NOX	CO2
GRAMS:	35MPH	3.33	27.93	2.47	1357.07
	55MPH	3.06	25.93	13.20	2264.38
GRAMS/MILE:	35MPH	1.14	9.57	0.85	465.23
	55MPH	0.67	5.66	2.88	494.08

MILES/GALLON: 35MPH 18.34
55MPH 17.57

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 7

HOOKER TUNED EXHAUST HEADERS, FIRST REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0029

		HC	CO	NOX	CO2
GRAMS:	COLD	8.86	132.22	17.80	2665.79
	STABILIZED	7.19	144.30	13.30	2930.32
	HOT	6.67	113.85	20.17	2467.18
GRAMS/MILE:	COMPOSITE	1.97	35.47	4.33	731.05
MILES/GALLON:	11.19				

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0030

		HC	CO	NOX	CO2
GRAMS:		8.93	195.20	47.46	5136.62
GRAMS/MILE:		0.87	19.06	4.63	501.53
MILES/GALLON:	16.61				

STEADY STATE — RUN NUMBER 2B0031

			HC	CO	NOX	CO2
GRAMS:	35MPH		3.21	98.72	5.28	1237.15
	55MPH		2.95	72.86	16.41	2011.96
GRAMS/MILE:	35MPH		1.10	33.84	1.81	424.12
	55MPH		0.64	15.90	3.58	439.01
MILES/GALLON:	35MPH	18.46				
	55MPH	19.04				

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 8

HOOKER TUNED EXHAUST HEADERS, SECOND REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0033

		HC	CO	NOX	CO2
GRAMS:	COLD	7.76	119.87	16.73	2523.84
	STABILIZED	6.53	96.16	12.68	2694.07
	HOT	5.99	68.77	18.06	2156.37
GRAMS/MILE:	COMPOSITE	1.77	24.92	4.02	667.79

MILES/GALLON: 12.46

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0034

	HC	CO	NOX	CO2
GRAMS:	9.25	93.18	25.59	4910.54
GRAMS/MILE:	0.90	9.10	2.50	479.45

MILES/GALLON: 17.87

STEADY STATE — RUN NUMBER 2B0035

		HC	CO	NOX	CO2
GRAMS:	35MPH	2.96	31.21	2.57	1311.77
	55MPH	2.70	30.61	12.49	2228.62
GRAMS/MILE:	35MPH	1.02	10.70	0.88	449.70
	55MPH	0.59	6.68	2.73	486.28

MILES/GALLON: 35MPH 18.89
55MPH 17.80

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 9

BASELINE, THIRD REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0037

		HC	CO	NOX	CO2
GRAMS:	COLD	7.84	96.37	9.99	2642.03
	STABILIZED	6.19	51.61	6.33	2865.50
	HOT	5.89	45.76	10.13	2247.15
GRAMS/MILE:	COMPOSITE	1.72	15.88	2.19	704.33
MILES/GALLON:	12.08				

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0038

	HC	CO	NOX	CO2
GRAMS:	7.96	66.98	27.85	4961.51
GRAMS/MILE:	0.78	6.54	2.72	484.43
MILES/GALLON: 17.85				

STEADY STATE — RUN NUMBER 2B0039

			HC	CO	NOX	CO2
GRAMS:	35MPH		2.51	18.96	2.28	1294.85
	55MPH		2.18	22.17	13.29	2218.31
GRAMS/MILE:	35MPH		0.86	6.50	0.78	443.90
	55MPH		0.48	4.84	2.90	484.03
MILES/GALLON:	35MPH	19.43				
	55MPH	18.00				

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 10

BASELINE, FOURTH REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0041

		HC	CO	NOX	CO2
GRAMS:	COLD	7.59	97.25	9.71	2589.04
	STABILIZED	5.55	47.69	6.49	2847.81
	HOT	5.95	38.18	10.40	2227.17
GRAMS/MILE:	COMPOSITE	1.63	14.84	2.21	697.41
MILES/GALLON:	12.23				

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0042

		HC	CO	NOX	CO2
GRAMS:		7.79	44.63	27.55	4955.98
GRAMS/MILE:		0.76	4.36	2.69	483.89
MILES/GALLON:	18.00				

STEADY STATE — RUN NUMBER 2B0043

			HC	CO	NOX	CO2
GRAMS:	35MPH		2.13	15.66	2.36	1298.01
	55MPH		1.83	15.51	13.04	2226.02
GRAMS/MILE:	35MPH		0.73	5.37	0.81	444.98
	55MPH		0.40	3.39	2.84	485.71
MILES/GALLON:	35MPH	19.48				
	55MPH	18.03				

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 11

MSD, STOCK (0.050") CARBURETOR JETS, FIRST REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0045

		HC	CO	NOX	CO2
GRAMS:	COLD	6.52	98.88	11.30	2811.66
	STABILIZED	4.07	70.13	8.01	3169.24
	HOT	3.70	61.84	11.76	2466.59
GRAMS/MILE:	COMPOSITE	1.20	19.72	2.61	771.23

MILES/GALLON: 11.01

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0046

	HC	CO	NOX	CO2
GRAMS:	3.73	87.54	30.91	5177.00
GRAMS/MILE:	0.36	8.55	3.02	505.47

MILES/GALLON: 17.07

STEADY STATE — RUN NUMBER 2B0047

		HC	CO	NOX	CO2
GRAMS:	35MPH	1.67	23.15	2.60	1316.15
	55MPH	1.39	17.79	15.18	2295.02
GRAMS/MILE:	35MPH	0.57	7.94	0.89	451.20
	55MPH	0.30	3.88	3.31	500.77

MILES/GALLON:	35MPH	19.07
	55MPH	17.48

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 12

MSD, STOCK (0.050") CARBURETOR JETS, SECOND REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0051

		HC	CO	NOX	CO2
GRAMS:	COLD	8.45	112.26	11.96	2931.59
	STABILIZED	4.08	72.85	7.90	3308.84
	HOT	4.18	45.02	12.03	2518.26
GRAMS/MILE:	COMPOSITE	1.35	19.57	2.65	800.64

MILES/GALLON: 10.62

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0052

	HC	CO	NOX	CO2
GRAMS:	3.94	45.18	31.74	5175.98
GRAMS/MILE:	0.38	4.41	3.10	505.37

MILES/GALLON: 17.28

STEADY STATE — RUN NUMBER 2B0053

		HC	CO	NOX	CO2
GRAMS:	35MPH	1.85	21.69	2.60	1340.44
	55MPH	1.49	13.41	14.82	2330.89
GRAMS/MILE:	35MPH	0.63	7.43	0.89	459.53
	55MPH	0.33	2.93	3.23	508.59

MILES/GALLON: 35MPH 18.76
55MPH 17.26

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 13

MSD, LEANER (0.048") CARBURETOR JETS, FIRST REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0055

		HC	CO	NOX	CO2
GRAMS:	COLD	10.86	113.15	11.11	2914.19
	STABILIZED	4.38	46.34	6.93	3060.54
	HOT	3.95	36.80	11.11	2408.95
GRAMS/MILE:	COMPOSITE	1.51	15.46	2.41	758.23
MILES/GALLON:	11.27				

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0056

	HC	CO	NOX	CO2
GRAMS:	5.60	43.43	27.59	5223.67
GRAMS/MILE:	0.55	4.24	2.69	510.02
MILES/GALLON: 17.12				

STEADY STATE — RUN NUMBER 2B0057

			HC	CO	NOX	CO2
GRAMS:	35MPH		1.56	19.28	2.82	1372.26
	55MPH		1.40	12.05	12.79	2392.60
GRAMS/MILE:	35MPH		0.53	6.61	0.97	470.43
	55MPH		0.31	2.63	2.77	522.06
MILES/GALLON:	35MPH	18.39				
	55MPH	16.84				

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 14

CARBURETOR JETS, SECOND REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0061

		HC	CO	NOX	CO2
GRAMS:	COLD	10.36	100.86	11.02	2892.42
	STABILIZED	4.17	43.85	6.98	3049.47
	HOT	3.94	58.53	10.53	2430.95
GRAMS/MILE:	COMPOSITE	1.45	16.08	2.36	757.18
MILES/GALLON:	11.28				

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0062

		HC	CO	NOX	CO2
GRAMS:		4.75	41.85	27.34	5148.80
GRAMS/MILE:		0.46	4.09	2.67	502.71
MILES/GALLON:	17.38				

STEADY STATE — RUN NUMBER 2B0063

		HC	CO	NOX	CO2
GRAMS:	35MPH	1.81	18.13	2.66	1353.25
	55MPH	1.46	12.25	13.08	2367.87
GRAMS/MILE:	35MPH	0.62	6.22	0.91	463.92
	55MPH	0.32	2.67	2.85	516.66
MILES/GALLON:	35MPH 18.66				
	55MPH 17.01				

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 15

BASELINE, FIFTH REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0067

		HC	CO	NOX	CO2
GRAMS:	COLD	14.93	380.51	8.18	2783.27
	STABILIZED	5.79	115.59	6.53	3086.38
	HOT	17.95	92.60	10.51	2404.66
GRAMS/MILE:	COMPOSITE	2.99	44.26	2.14	753.85

MILES/GALLON: 10.66

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0068

	HC	CO	NOX	CO2
GRAMS:	8.99	105.85	29.01	5194.79
GRAMS/MILE:	0.88	10.33	2.83	507.20

MILES/GALLON: 16.87

STEADY STATE — RUN NUMBER 2B0069

		HC	CO	NOX	CO2
GRAMS:	35MPH	2.14	50.72	1.77	1307.04
	55MPH	1.79	16.86	14.43	2332.29
GRAMS/MILE:	35MPH	0.73	17.39	0.61	448.08
	55MPH	0.39	3.68	3.15	508.90

MILES/GALLON: 35MPH 18.58
55MPH 17.20

TABLE A-1. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - TEST RESULTS (Continued)

TEST SEQUENCE 16

BASELINE, SIXTH REPLICATE

FEDERAL TESTING PROCEDURE — RUN NUMBER 2B0072

		HC	CO	NOX	CO2
GRAMS:	COLD	10.77	110.45	11.68	2859.89
	STABILIZED	6.07	43.02	7.29	2955.96
	HOT	5.33	43.21	11.06	2343.81
GRAMS/MILE:	COMPOSITE	1.83	15.35	2.48	736.22

MILES/GALLON: 11.58

FEDERAL HIGHWAY FUEL ECONOMY TEST — RUN NUMBER 2B0073

	HC	CO	NOX	CO2
GRAMS:	7.80	46.54	29.04	5101.51
GRAMS/MILE:	0.76	4.54	2.84	498.10

MILES/GALLON: 17.48

STEADY STATE — RUN NUMBER 2B0074

		HC	CO	NOX	CO2
GRAMS:	35MPH	2.37	20.82	2.61	1315.76
	55MPH	2.07	13.05	13.43	2338.74
GRAMS/MILE:	35MPH	0.81	7.14	0.90	451.07
	55MPH	0.45	2.85	2.93	510.31

MILES/GALLON: 35MPH 19.09
55MPH 17.19

TABLE A-2. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - STATISTICAL ANALYSIS

CONFIGURATION= BASELINE

	PARAMETER	REPLI CATES	MEAN	STANDARD DEVIATION	PCDEV	95PC CONF.INT.
TEST PROCEDURE= FTP						
	FE BAG1	6	10.75	.849	7.90	9.86 - 11.64
	FE BAG2	6	11.16	.708	6.34	10.42 - 11.91
	FE BAG3	6	12.98	.796	6.13	12.15 - 13.82
	FE COMP	6	11.51	.720	6.26	10.75 - 12.26
	HC BAG1	6	3.09	.821	26.56	2.23 - 3.96
	HC BAG2	6	1.81	.494	27.29	1.29 - 2.33
	HC BAG3	6	2.43	1.324	54.56	1.04 - 3.82
	HC COMP	6	2.24	.591	26.37	1.62 - 2.86
	CO BAG1	6	48.16	31.328	65.05	15.28 - 81.04
	CO BAG2	6	23.05	13.563	58.83	8.82 - 37.29
	CO BAG3	6	20.74	13.283	64.05	6.80 - 34.68
	CO COMP	6	27.59	15.401	55.82	11.42 - 43.75
	NOX BAG1	6	3.11	.716	23.04	2.36 - 3.86
	NOX BAG2	6	1.86	.260	13.98	1.59 - 2.13
	NOX BAG3	6	3.30	.607	18.39	2.66 - 3.94
	NOX COMP	6	2.51	.430	17.11	2.06 - 2.96
TEST PROCEDURE= HWFET						
	FE	6	17.22	.640	3.72	16.55 - 17.90
	HC	6	.87	.286	32.95	.57 - 1.17
	CO	6	11.39	8.871	77.90	2.08 - 20.70
	NOX	6	2.63	.232	8.82	2.39 - 2.87
TEST PROCEDURE= STEADY STATE, 35 MPH						
	FE	6	19.16	.673	3.51	18.45 - 19.86
	HC	6	.79	.179	22.50	.61 - .98
	CO	6	10.82	5.102	47.15	5.47 - 16.18
	NOX	6	.76	.129	16.88	.63 - .90
TEST PROCEDURE= STEADY STATE, 55 MPH						
	FE	6	17.34	.645	3.72	16.66 - 18.01
	HC	6	.49	.223	45.83	.25 - .72
	CO	6	3.66	.721	19.66	2.91 - 4.42
	NOX	6	3.17	.822	25.95	2.30 - 4.03

PCDEV = PERCENT DEVIATION FROM THE MEAN.

95PC CONF.INT. = CONFIDENCE INTERVAL FOR THE MEAN.

FE = FUEL ECONOMY IN MILES PER GALLON.

COMP = COMPOSITE FTP RESULTS.

ALL EMISSIONS ARE IN GRAM/MILE

TABLE A-2. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - STATISTICAL ANALYSIS (Continued)

CONFIGURATION= EDELBROCK INLET MANIFOLD

	PARAMETER	REPLI CATES	MEAN	STANDARD DEVIATION	PCDEV	95PC CONF.INT.
TEST PROCEDURE= FTP						
	FE BAG1	2	10.52	.021	.20	10.33 - 10.72
	FE BAG2	2	10.12	.509	5.03	5.55 - 14.69
	FE BAG3	2	12.16	.417	3.43	8.42 - 15.91
	FE COMP	2	10.69	.396	3.70	7.13 - 14.25
	HC BAG1	2	2.91	.403	13.87	-.72 - 6.53
	HC BAG2	2	1.63	.120	7.40	.54 - 2.71
	HC BAG3	2	1.56	.042	2.72	1.18 - 1.94
	HC COMP	2	1.87	.156	8.32	.47 - 3.27
	CO BAG1	2	39.77	4.716	11.86	-2.60 - 82.15
	CO BAG2	2	24.27	.191	.79	22.56 - 25.99
	CO BAG3	2	22.83	8.881	38.90	-56.96 - 102.62
	CO COMP	2	27.07	3.295	12.17	-2.53 - 56.67
	NOX BAG1	2	3.27	.856	26.21	-4.42 - 10.95
	NOX BAG2	2	2.50	.092	3.68	1.67 - 3.32
	NOX BAG3	2	3.82	.976	25.54	-4.95 - 12.59
	NOX COMP	2	3.02	.488	16.18	-1.37 - 7.40
TEST PROCEDURE= HWFET						
	FE	2	17.71	.297	1.68	15.04 - 20.38
	HC	2	.61	.021	3.45	.42 - .81
	CO	2	12.28	3.465	28.22	-18.85 - 43.41
	NOX	2	2.77	.792	28.59	-4.35 - 9.89
TEST PROCEDURE= STEADY STATE, 35 MPH						
	FE	2	19.47	.262	1.34	17.12 - 21.83
	HC	2	.84	.134	15.90	-.36 - 2.05
	CO	2	7.47	.403	5.40	3.84 - 11.09
	NOX	2	.80	.177	21.96	-.78 - 2.39
TEST PROCEDURE= STEADY STATE, 55 MPH						
	FE	2	17.62	.148	.84	16.28 - 18.95
	HC	2	.49	.099	20.20	-.40 - 1.38
	CO	2	7.76	2.022	26.06	-10.41 - 25.93
	NOX	2	3.48	.898	25.84	-4.59 - 11.54

TABLE A-2. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - STATISTICAL ANALYSIS (Continued)

CONFIGURATION= EDELBROCK INLET MANIFOLD PLUS HOOKER TUNED EXHAUST HEADERS

	PARAMETER	REPLICATES	MEAN	STANDARD DEVIATION	PCDEV	95PC CONF.INT.
TEST PROCEDURE= FTP						
	FE BAG1	2	10.83	.354	3.26	7.65 - 14.01
	FE BAG2	2	10.52	.120	1.14	9.44 - 11.61
	FE BAG3	2	12.21	.445	3.65	8.21 - 16.22
	FE COMP	2	11.00	.240	2.19	8.84 - 13.16
	HC BAG1	2	2.79	.368	13.18	-.51 - 6.09
	HC BAG2	2	2.10	.113	5.39	1.08 - 3.12
	HC BAG3	2	1.94	.057	2.92	1.43 - 2.45
	HC COMP	2	2.20	.156	7.07	.80 - 3.60
	CO BAG1	2	30.22	7.396	24.47	-36.23 - 96.67
	CO BAG2	2	27.10	.693	2.56	20.87 - 33.33
	CO BAG3	2	20.10	3.932	19.56	-15.22 - 55.42
	CO COMP	2	25.83	2.963	11.47	-.78 - 52.45
	NOX BAG1	2	3.04	.184	6.05	1.39 - 4.69
	NOX BAG2	2	1.95	.078	4.00	1.25 - 2.64
	NOX BAG3	2	3.53	.177	5.01	1.94 - 5.11
	NOX COMP	2	2.60	.057	2.18	2.09 - 3.11
TEST PROCEDURE= HWFET						
	FE	2	16.69	.834	5.00	9.19 - 24.19
	HC	2	.93	.099	10.64	.04 - 1.82
	CO	2	14.38	5.042	35.05	-30.91 - 59.68
	NOX	2	2.75	.148	5.39	1.42 - 4.09
TEST PROCEDURE= STEADY STATE, 35 MPH						
	FE	2	18.62	.396	2.13	15.06 - 22.18
	HC	2	1.04	.134	12.86	-.16 - 2.25
	CO	2	12.25	3.790	30.94	-21.80 - 46.30
	NOX	2	.74	.156	21.02	-.66 - 2.14
TEST PROCEDURE= STEADY STATE, 55 MPH						
	FE	2	17.46	.163	.93	15.99 - 18.92
	HC	2	.70	.049	7.02	.26 - 1.15
	CO	2	10.60	6.986	65.91	-52.17 - 73.37
	NOX	2	2.57	.431	16.75	-1.30 - 6.45

TABLE A-2. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - STATISTICAL ANALYSIS (Continued)

CONFIGURATION= HOOKER TUNED EXHAUST HEADERS

	PARAMETER	REPLICATES	MEAN	STANDARD DEVIATION	PCDEV	95PC CONF.INT.
TEST PROCEDURE= FTP						
	FE BAG1	2	11.31	.467	4.13	7.12 - 15.50
	FE BAG2	2	11.51	.849	7.37	3.89 - 19.13
	FE BAG3	2	12.95	1.414	10.92	.24 - 25.66
	FE COMP	2	11.82	.898	7.59	3.76 - 19.89
	HC BAG1	2	2.31	.219	9.47	.35 - 4.28
	HC BAG2	2	1.76	.120	6.85	.67 - 2.84
	HC BAG3	2	1.77	.134	7.61	.56 - 2.97
	HC COMP	2	1.87	.141	7.56	.60 - 3.14
	CO BAG1	2	35.11	2.432	6.93	13.26 - 56.96
	CO BAG2	2	30.75	8.704	28.31	-47.46 - 108.95
	CO BAG3	2	25.43	8.874	34.89	-54.30 - 105.17
	CO COMP	2	30.19	7.460	24.71	-36.83 - 97.22
	NOX BAG1	2	4.81	.212	4.41	2.90 - 6.72
	NOX BAG2	2	3.32	.113	3.41	2.30 - 4.34
	NOX BAG3	2	5.32	.417	7.83	1.58 - 9.07
	NOX COMP	2	4.18	.219	5.25	2.21 - 6.14
TEST PROCEDURE= HWFET						
	FE	2	17.24	.891	5.17	9.24 - 25.24
	HC	2	.88	.021	2.40	.69 - 1.08
	CO	2	14.08	7.043	50.02	-49.20 - 77.36
	NOX	2	3.56	1.506	42.25	-9.97 - 17.10
TEST PROCEDURE= STEADY STATE, 35 MPH						
	FE	2	18.67	.304	1.63	15.94 - 21.41
	HC	2	1.06	.057	5.34	.55 - 1.57
	CO	2	22.27	16.362	73.47	*24.74 - 169.28
	NOX	2	1.34	.658	48.89	-4.56 - 7.25
TEST PROCEDURE= STEADY STATE, 55 MPH						
	FE	2	18.42	.877	4.76	10.54 - 26.30
	HC	2	.61	.035	5.75	.30 - .93
	CO	2	11.29	6.520	57.75	-47.28 - 69.86
	NOX	2	3.16	.601	19.05	-2.25 - 8.56

TABLE A-2. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - STATISTICAL ANALYSIS (Continued)

CONFIGURATION= MSD DEVICE, STANDARD A/F

	PARAMETER	REPLI CATES	MEAN	STANDARD DEVIATION	PCDEV	95PC CONF.INT.
TEST PROCEDURE= FTP						
	FE BAG1	2	10.41	.354	3.40	7.23 - 13.59
	FE BAG2	2	10.32	.311	3.01	7.52 - 13.12
	FE BAG3	2	12.31	.092	.75	11.48 - 13.13
	FE COMP	2	10.81	.276	2.55	8.34 - 13.29
	HC BAG1	2	2.08	.375	17.97	-1.28 - 5.45
	HC BAG2	2	1.04	0.000	0.00	1.04 - 1.04
	HC BAG3	2	1.09	.092	8.39	.27 - 1.92
	HC COMP	2	1.27	.106	8.32	.32 - 2.23
	CO BAG1	2	29.40	2.638	8.97	5.71 - 53.10
	CO BAG2	2	18.28	.488	2.67	13.90 - 22.67
	CO BAG3	2	14.88	3.316	22.28	-14.91 - 44.68
	CO COMP	2	19.64	.106	.54	18.69 - 20.60
	NOX BAG1	2	3.24	.127	3.93	2.10 - 4.38
	NOX BAG2	2	2.03	.021	1.04	1.84 - 2.23
	NOX BAG3	2	3.31	.049	1.49	2.87 - 3.76
	NOX COMP	2	2.63	.028	1.08	2.38 - 2.88
TEST PROCEDURE= HWFET						
	FE	2	17.17	.148	.86	15.84 - 18.51
	HC	2	.37	.014	3.82	.24 - .50
	CO	2	6.48	2.927	45.18	-19.82 - 32.78
	NOX	2	3.06	.057	1.85	2.55 - 3.57
TEST PROCEDURE= STEADY STATE, 35 MPH						
	FE	2	18.91	.219	1.16	16.95 - 20.88
	HC	2	.60	.042	7.07	.22 - .98
	CO	2	7.69	.361	4.69	4.44 - 10.93
	NOX	2	.89	0.000	0.00	.89 - .89
TEST PROCEDURE= STEADY STATE, 55 MPH						
	FE	2	17.37	.156	.90	15.97 - 18.77
	HC	2	.31	.021	6.73	.12 - .51
	CO	2	3.41	.672	19.73	-2.63 - 9.44
	NOX	2	3.27	.057	1.73	2.76 - 3.78

TABLE A-2. CHASSIS DYNAMOMETER TESTING OF RETROFIT DEVICES - STATISTICAL ANALYSIS (Continued)

CONFIGURATION= MSD DEVICE, LEANER A/F

	PARAMETER	REPLI CATES	MEAN	STANDARD DEVIATION	PCDEV	95PC CONF.INT.
TEST PROCEDURE= FTP						
	FE BAG1	2	10.26	.099	.96	9.37 - 11.15
	FE BAG2	2	11.05	.035	.32	10.74 - 11.37
	FE BAG3	2	12.71	.198	1.56	10.93 - 14.49
	FE COMP	2	11.27	.007	.06	11.21 - 11.34
	HC BAG1	2	2.95	.092	3.11	2.13 - 3.78
	HC BAG2	2	1.09	.035	3.23	.78 - 1.41
	HC BAG3	2	1.10	0.000	0.00	1.10 - 1.10
	HC COMP	2	1.48	.042	2.87	1.10 - 1.86
	CO BAG1	2	29.80	2.425	8.14	8.01 - 51.60
	CO BAG2	2	11.54	.445	3.86	7.53 - 15.54
	CO BAG3	2	13.27	4.278	32.23	-25.16 - 51.71
	CO COMP	2	15.77	.438	2.78	11.83 - 19.71
	NOX BAG1	2	3.08	.021	.69	2.89 - 3.28
	NOX BAG2	2	1.78	.014	.79	1.65 - 1.91
	NOX BAG3	2	3.01	.113	3.76	1.99 - 4.03
	NOX COMP	2	2.38	.035	1.48	2.07 - 2.70
TEST PROCEDURE= HWFET						
	FE	2	17.25	.184	1.07	15.60 - 18.90
	HC	2	.50	.064	12.60	-.07 - 1.08
	CO	2	4.16	.106	2.55	3.21 - 5.12
	NOX	2	2.68	.014	.53	2.55 - 2.81
TEST PROCEDURE= STEADY STATE, 35 MPH						
	FE	2	18.52	.191	1.03	16.81 - 20.24
	HC	2	.57	.064	11.07	.00 - 1.15
	CO	2	6.41	.276	4.30	3.94 - 8.89
	NOX	2	.94	.042	4.51	.56 - 1.32
TEST PROCEDURE= STEADY STATE, 55 MPH						
	FE	2	16.92	.120	.71	15.84 - 18.01
	HC	2	.31	.007	2.24	.25 - .38
	CO	2	2.65	.028	1.07	2.40 - 2.90
	NOX	2	2.81	.057	2.01	2.30 - 3.32

APPENDIX B

REPORT OF INVENTIONS

Since this work was limited to a test evaluation of existing, automotive aftermarket retrofit devices, no new innovation, improvement or invention was discovered or developed in this contract effort. However, the work does provide significant new findings regarding the fuel economy improvement potential of a wide variety of retrofit hardware frequently offered for sale with claims of fuel savings and performance improvement. None of the devices evaluated showed a significant gain in fuel economy under driving conditions likely to be encountered in average street or highway use.