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Evaluation of the Micro-Carburetor

Merkel F. Weiss
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ABSTRACT

A prototype sonic, variable-venturi automotive carburetor, developed by Micro Carburetor Corporation, has been evaluated for its effects on vehicle performance, fuel economy, and exhaust emissions. A 350 CID Chevrolet Impala vehicle was tested on a chassis dynamometer over the 1975 Federal Test Procedure, urban driving cycle. The Micro-carburetor was tested and compared with stock and modified-stock engine configurations. Subsequently, the test vehicle's performance characteristics were examined with the stock carburetor and again with the Micro-carburetor in a series of on-road driveability tests. The test engine was then removed from the vehicle and installed on an engine dynamometer. Engine tests were conducted to compare the fuel economy, thermal efficiency, and cylinder-to-cylinder mixture distribution of the Micro-carburetor to that of the stock configuration.

Test results show increases in thermal efficiency and improvements in fuel economy at all test conditions. The Micro-carburetor fuel economy improvement ranged from 9.7% (cold-start FTP, equal spark advance) to 18.1% (hot-start FTP, equal spark advance). Cylinder-to-cylinder mixture distribution improvements were observed. Potential reductions in exhaust emissions are also indicated.

Improved fuel/air mixture preparation is implied from the information presented. Further improvements in fuel economy and exhaust emissions are possible through a detailed recalibration of the Micro-carburetor.

ACKNOWLEDGMENT

The authors wish to acknowledge the contributions made by L. E. Baughman, Task Manager, Transportation Systems Project, D. A. Brown and R. L. Hewitt for data-processing services, and J. R. Allison and R. E. Burleson for test operation, instrumentation, and data-gathering support.

ACRONYMS AND ABBREVIATIONS

AFR	Air/Fuel Ratio (lbm air)/(lbm fuel)
BDC	Bottom Dead Center Piston Position
bhp	Brake Horsepower
bmep	Brake Mean Effective Pressure (psi)
bsfc	Brake Specific Fuel Consumption (lbm/bhp-hr)
CO	Carbon Monoxide Exhaust Emissions
EFE	Early Fuel Evaporation
EPA	U. S. Environmental Protection Agency
EGR	Exhaust Gas Recirculation
fhp	Friction Horsepower
FTP	1975 Federal Test Procedure, Urban Driving Cycle (EPA Mandated for Emissions Certification of New Cars)
HC	Unburned Hydrocarbon Exhaust Emissions
lbm	Pounds Mass
NO_x	Oxides of Nitrogen
PCV	Positive Crankcase Ventilation
rpm	Revolutions per Minute
TDC	Top Dead Center Piston Position
WOT	Wide Open Throttle
ϕ	Equivalence Ratio, $\phi = (AFR_{stoich})/(AFR_{actual})$
η_t	Thermal Efficiency (see Appendix D)
η_v	Volumetric Efficiency (see Appendix E)

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SECTION I

INTRODUCTION

The Micro Carburetor Corporation, located in Buffalo, New York, has developed a prototype automotive carburetor intended for use on existing automobile engines. The carburetor features a special "air valve," designed to finely atomize the fuel flow into the engine. The Micro-carburetor delivers a lean and near homogeneous air-fuel mixture in order to improve fuel economy.

The Jet Propulsion Laboratory was requested to evaluate the Micro-carburetor prototype for the Vehicle Peformance Branch of the Transportation Systems Utilization Division, Office of Transportation Programs, in the U. S. Department of Energy. The objective of the task was to perform an independent technical assessment of the Micro-carburetor system with controlled laboratory tests. Data were gathered with both the stock Rochester carburetor and the Micro-carburetor on engine performance, exhaust emissions, and fuel economy. A Chevrolet vehicle was equipped with each carburetor and operated over the 1975 Federal Test Procedure (FTP), urban driving cycle. The driving performance of the vehicle was then evaluated with each carburetor. The testing was performed as indicated on the milestone chart in Figure 1-1.

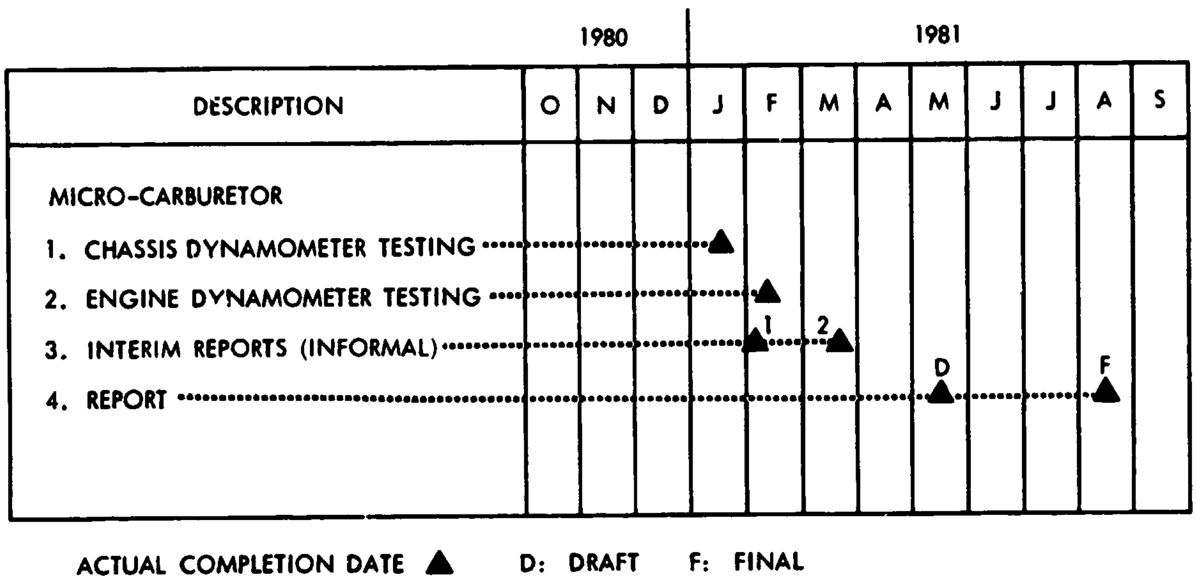


Figure 1-1. Milestone Chart

SECTION II

DESCRIPTION OF THE MICRO-CARBURETOR

A. BACKGROUND

The Micro-carburetor prototype tested by JPL is a single-barrel, sonic, variable-venturi carburetor (see Figure 2-1). Variable or slide-venturi carburetors are commonplace on motorcycle engines and have been used successfully in many production cars. Carburetors such as the SU and the Motorcraft VV share the same simplicity of basic operation despite being considerably different in construction. The Micro-carburetor does not use a conventional throttle plate. The minimum throat area of the metering venturi is varied to meter air to the engine. A special feature of the Micro-carburetor is the venturi throat, which is designed to permit the incoming air to reach sonic velocity (Ref. 1). The shock wave generated by this critical velocity is then used to finely atomize the incoming fuel spray. Therefore, the potential advantage of the Micro-carburetor would be its ability to create ultra-fine fuel particles that would distribute more evenly between the cylinders of the engine and thus allow the engine to operate leaner than stock. The following are potential benefits that may be gained over standard carburetion:

(1) Fuel savings due to the elimination of overfueling some cylinders in order to supply sufficient fuel to other leaner cylinders.

(2) Fuel savings resulting from an increase in thermal efficiency.

(3) Reduction in CO production from the suppression of overfueling.

(4) Reduction in unburned HC emissions stemming from a potential decrease in chamber wall wetting. The finer fuel particles should vaporize more easily.

(5) Reduction of NO_x production due to more uniform control of combustion temperatures throughout the engine.

B. DESIGN AND OPERATION

The carburetor throat shown in Figure 2-1 is the smallest annulus formed between the air valve and the carburetor main body. An upward axial motion of the valve "opens the throttle" for increased air flow. According to the Micro Carburetor Corporation (Ref. 1), sonic flow is achieved across the converging-diverging contour of the air valve throat with intake manifold vacuum above 6.5 inches of Hg. Fuel is delivered through small holes in the carburetor throat. Once issued, the tiny fuel streams are broken up by the sonic shock wave in the venturi and the fuel particles become entrained in the air flow. The flow then diverges and decelerates in the secondary diffuser section.

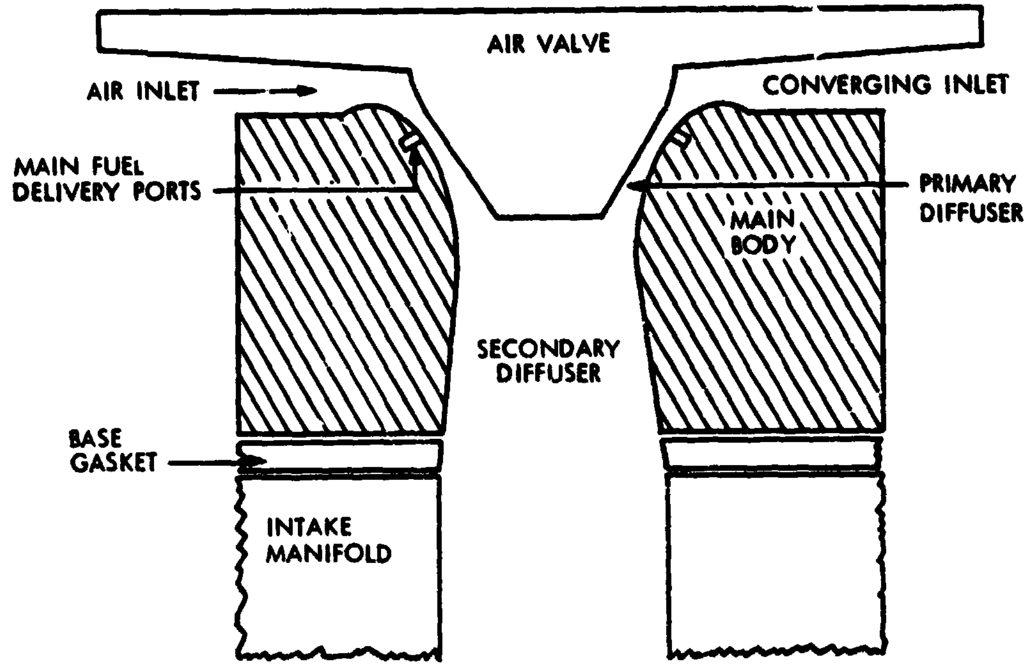
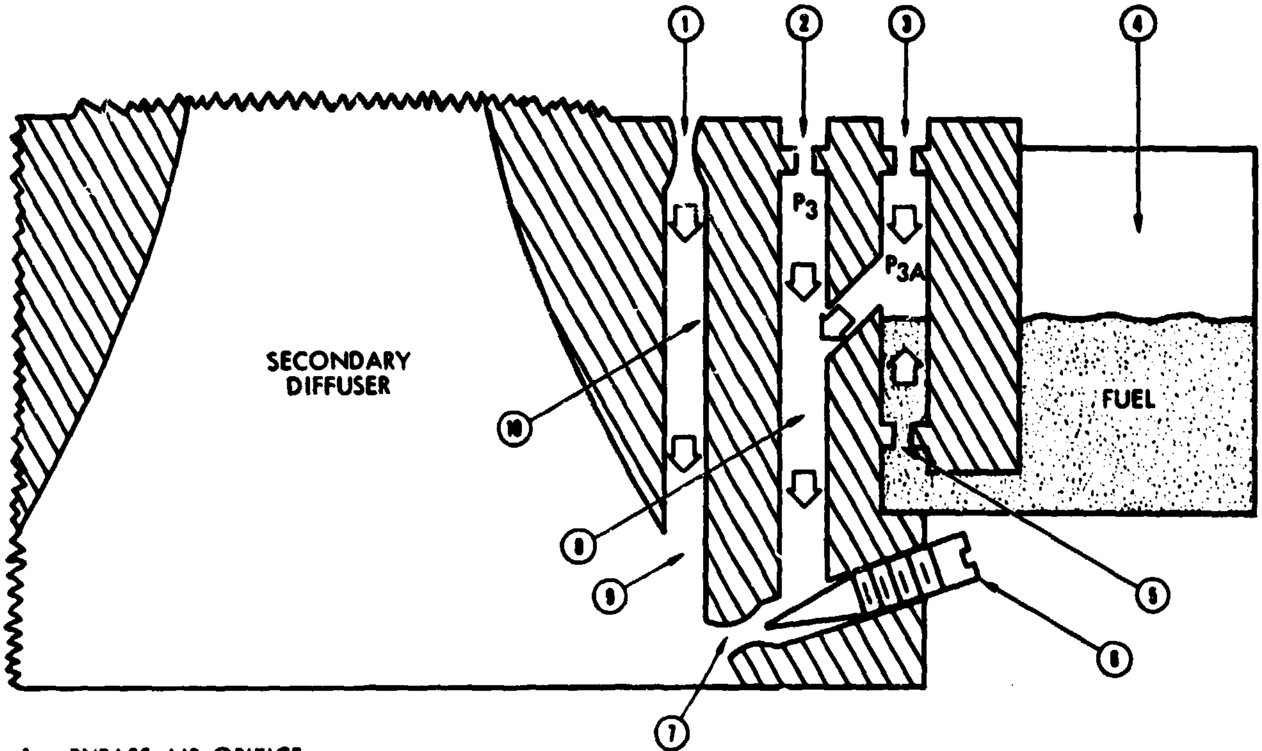


Figure 2-1. Micro-Carburetor Air Inlet Path Geometry

At idle, the local venturi vacuum is insufficient to draw fuel from the main fueling system. For this reason, an idle system is provided (Ref. 1) as shown schematically in Figure 2-2. The figure depicts fuel that is drawn by vacuum from the bowl (4) and metered in the idle feed restriction (5). Here fuel is entrained in metered air from the primary idle air bleed (3). The mixture becomes further atomized in the "down channel" (8) due to its interaction with the airstream from the secondary idle air bleed (2). The mixture volume is adjusted with a standard needle-valve type mixture screw (6). After delivery from the idle discharge port (7), the mixture is blown off of the diffuser wall and into the airstream by an idle-air bypass system (1,9,10). The bypass air is metered through an orifice (1) and delivered through the bypass port (9) just above the idle discharge port. This type of idle air bypass system has also been used successfully in carburetors with throttle plates to improve idle fuel atomization under adverse conditions. The Micro-carburetor has two complete idle circuits, one on each side of the diffuser base.



1. BYPASS AIR ORIFICE
2. SECONDARY IDLE AIR BLEED
3. PRIMARY IDLE AIR BLEED
4. BOWL
5. IDLE FEED RESTRICTION
6. IDLE MIXTURE SCREW
7. IDLE DISCHARGE PORT
8. DOWN CHANNEL
9. IDLE BYPASS PORT
10. BYPASS AIR DOWN CHANNEL

Figure 2-2. Micro-Carburetor Idle Circuit

Another unusual feature of the Micro-carburetor is the rotary choke system shown in Figure 2-3. The choke consists of two slotted concentric rings whose slots line up when in the "choke open" position. The inner choke ring is rotated against the fixed outer ring to align the desired amount of slot opening. Control of the inner ring is accomplished with a standard choke-heater device. The heater warms a bimetallic spring that uncoils at a calibrated torque per unit temperature change. This torque controls the inner choke ring rotation.

The choke ring motion is modulated by a "vacuum pull down" or "vacuum-break" system, shown in Figure 2-4. This system is simply a vacuum-powered dashpot in series with an extension spring. Immediately after startup, when ultra-rich cranking mixtures are no longer required, the vacuum-break system partially opens the choke to a set position. The choke position will modulate about this setting until the choke heater commands a greater choke aperture area. Many of the parts used for construction of the vacuum-break and choke-heater systems are parts taken from commonly-used carburetors.

The fast-idle system, shown in Figure 2-5, works in conjunction with the choke control to adjust the position of the air valve with engine temperature. Fast-idle is accomplished by lifting the air valve a varying amount according to the choke temperature. The choke temperature controls the position of the fast-idle cam, against which the idle-speed screw rests. This cam rotates to the top step when the engine is cold. As the engine warms, the cam rotates toward the bottom step. When the engine is fully warmed, curb idle may be set with the idle-speed screw against the bottom step of the fast idle cam.

As in most other carburetors, the Micro-carburetor has an accelerator pump circuit. The accelerator pump issues a solid fuel stream as the throttle is opened. This is done to provide fuel during the mechanical lag-time between the throttle command and the actual fuel delivery from the main fueling system. The fuel stream is metered by a commonly-used positive displacement diaphragm pump, shown in Figure 2-6. The accelerator pump is easily calibrated for pump shot volume and duration. The pump delivery may even be set in a nonlinear fashion by modifying the accelerator pump-cam profiles. Shown in Figure 2-7, this pump cam follows the throttle motion mechanically.

The float bowl and needle valve assembly are used to gather and maintain a fuel reservoir. This reservoir serves the supply and driving pressure head functions of the carburetor. The entire bowl assembly was taken from another well-known carburetor and simply grafted to the Micro-carburetor prototype.

Most carburetors provide a spark-advance strategy of the manufacturer's option. The spark-advance strategy for the Micro-carburetor involves direct manifold vacuum to the distributor vacuum advance. The baseline Rochester, on the other hand, has a ported spark system consisting of a vacuum tap located in the lower venturi section, just above the throttle plate at idle. No vacuum signal is available from the Rochester carburetor to the vacuum spark advance until off-idle, when the throttle plate sweeps past the vacuum port. The effects of the differences in spark-advance systems were isolated during the test procedure.

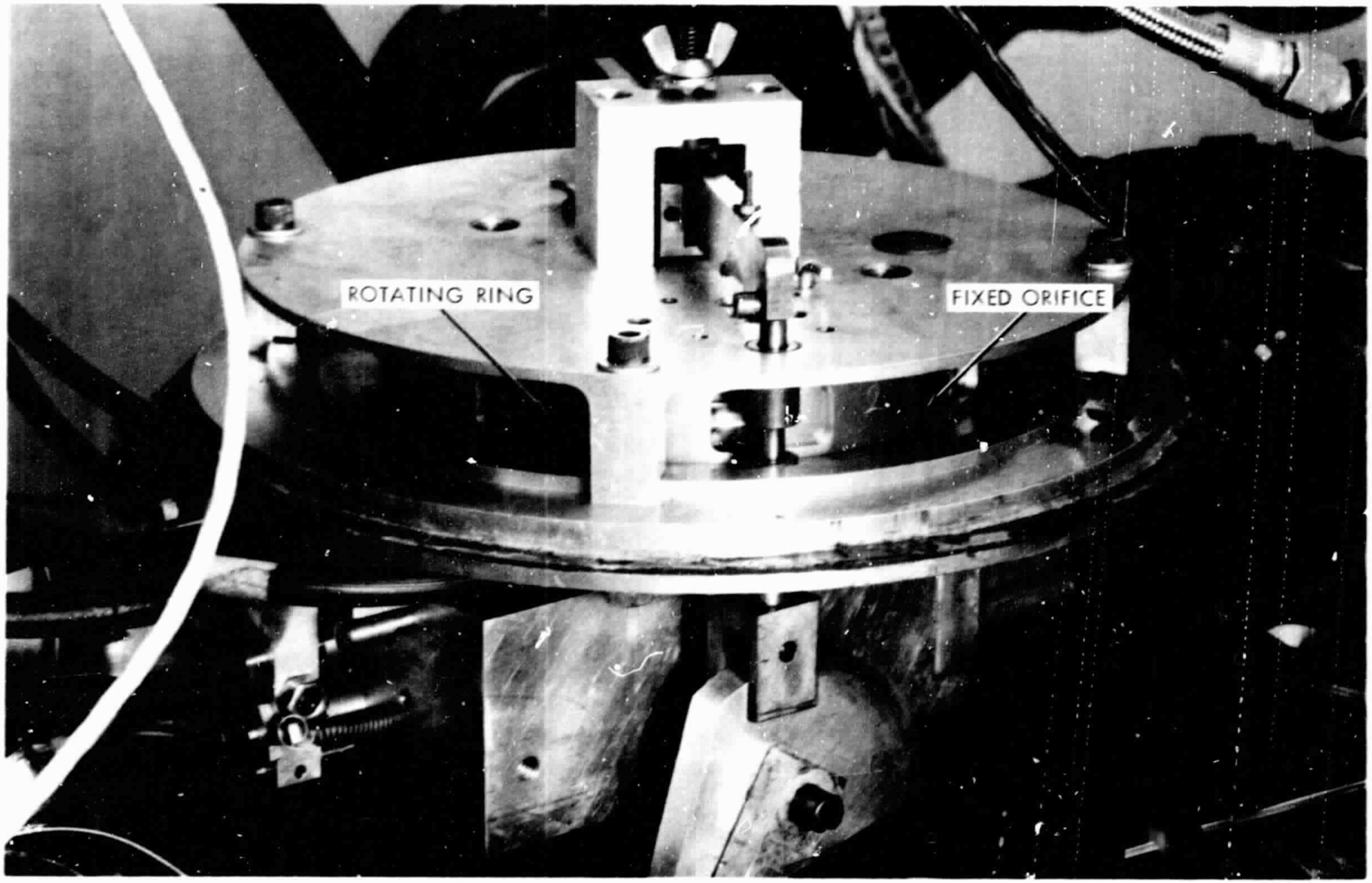


Figure 2-3. Micro-Carburetor Rotary Choke System

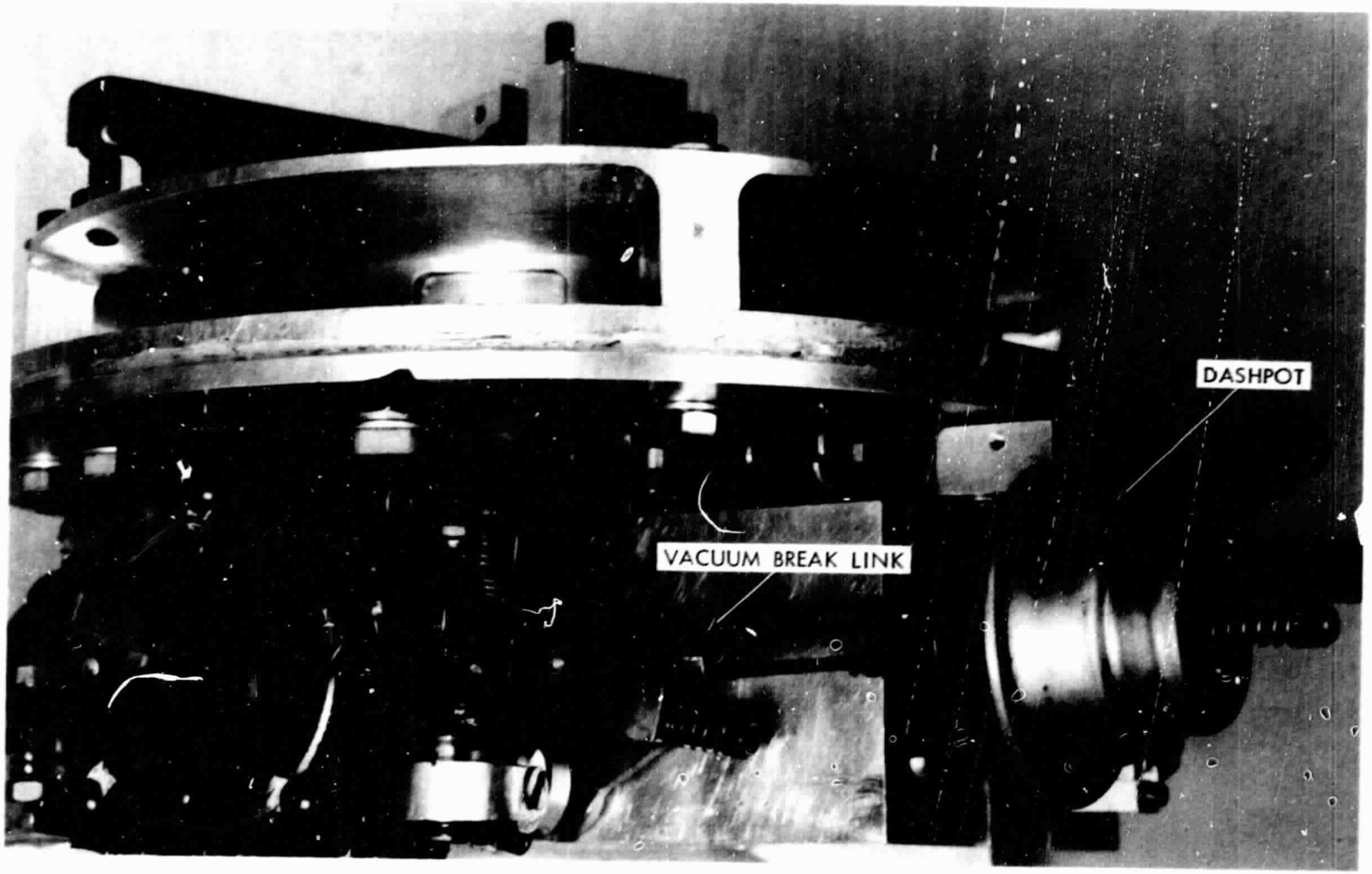


Figure 2-4. Micro-Carburetor Rotary Choke System - Vacuum Break System

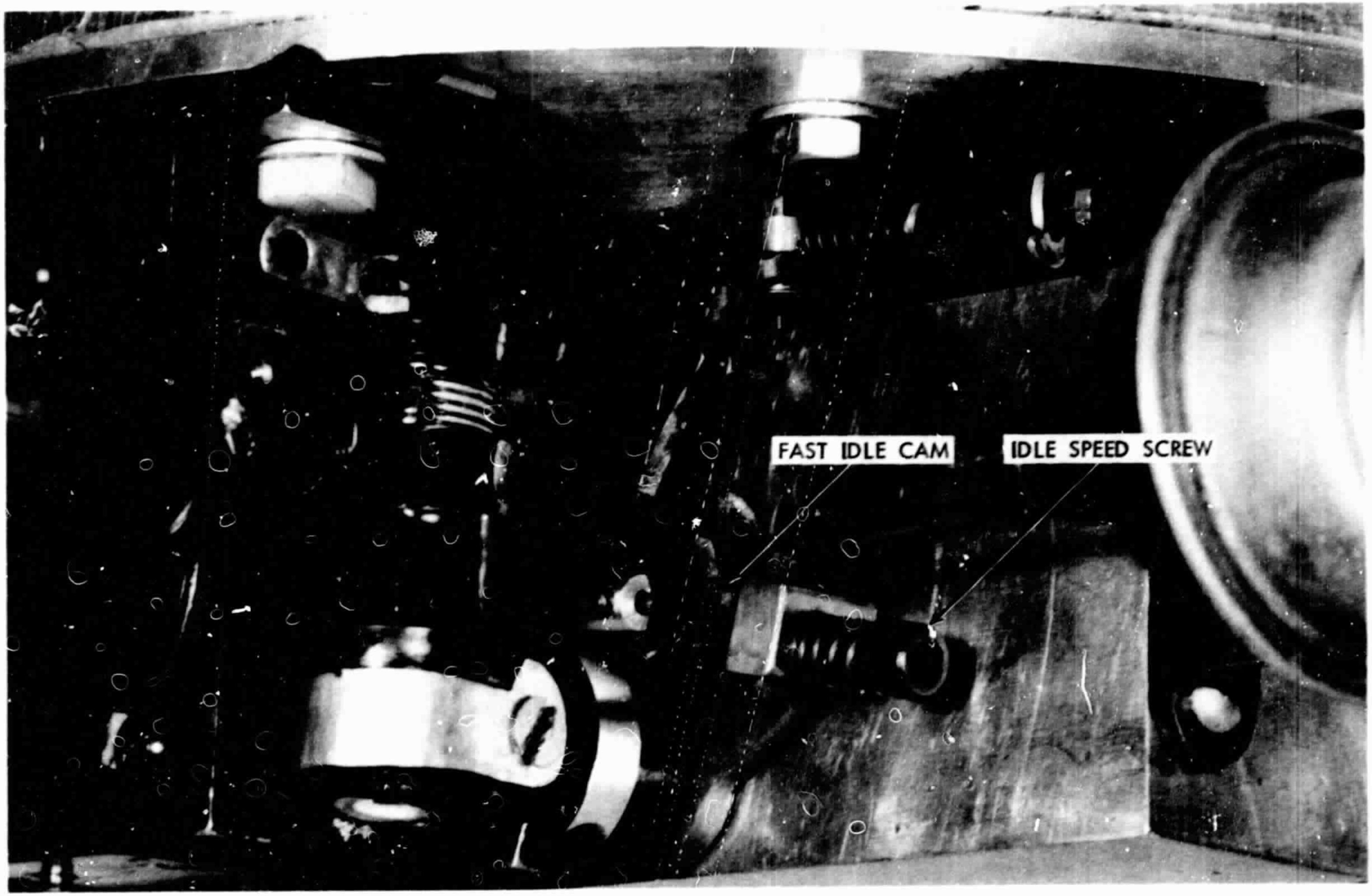


Figure 2-5. Micro-Carburetor Rotary Choke System - Fast Idle Cam

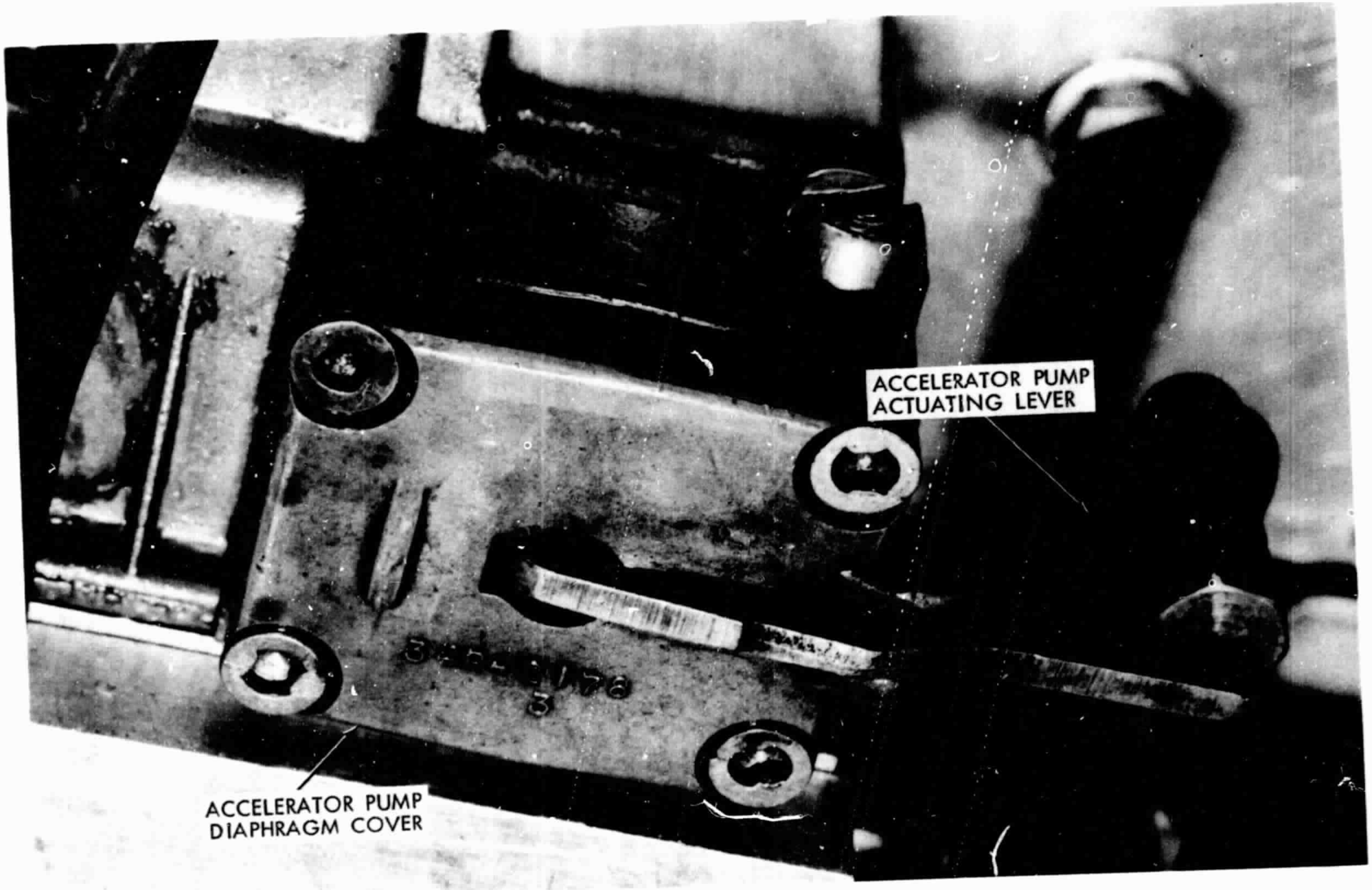


Figure 2-6. Micro-Carburetor Accelerator Pump Diaphragm Assembly

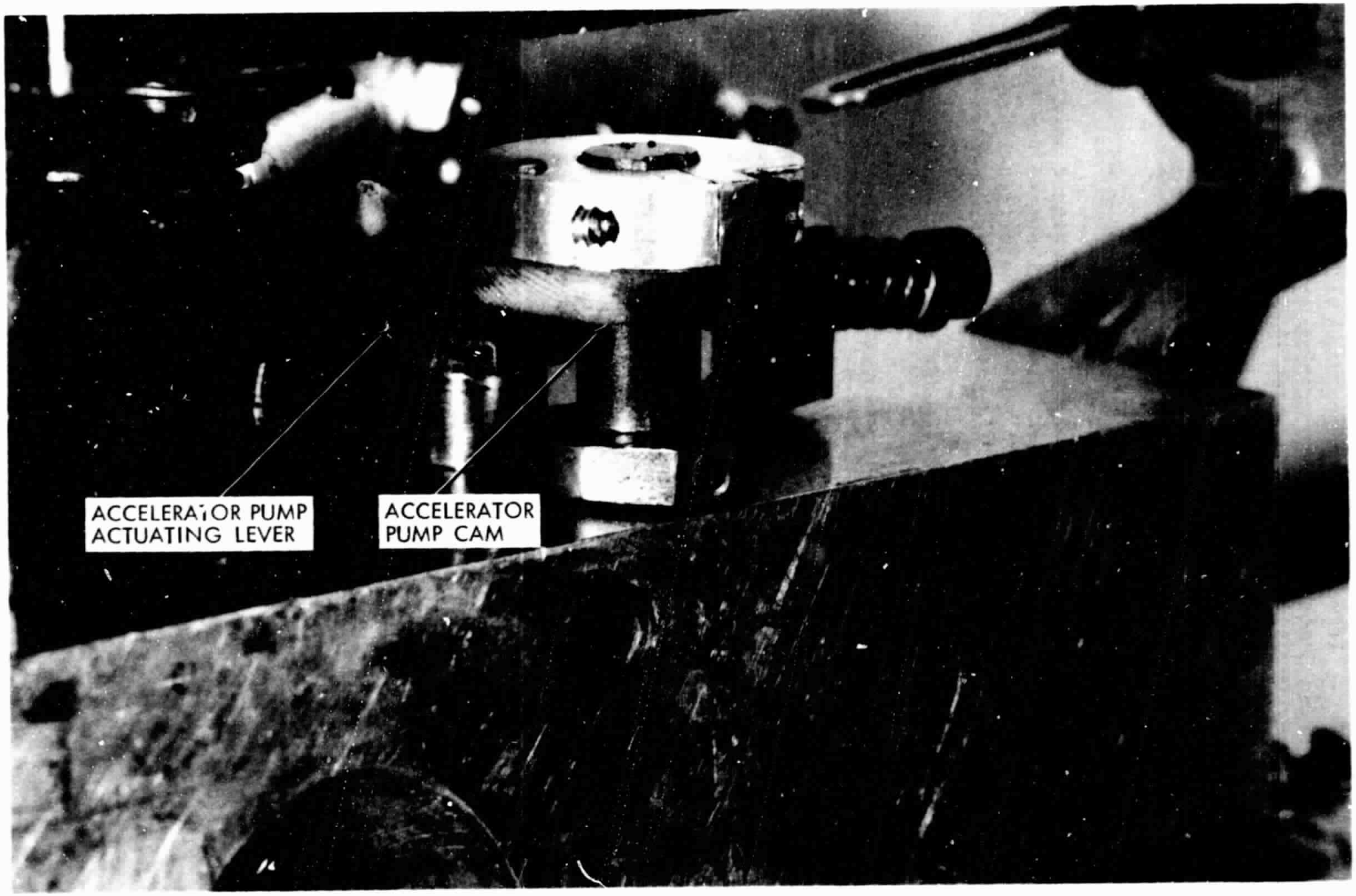


Figure 2-7. Micro-Carburetor Accelerator Pump Cam

For operation at higher loads, the carburetor has an enrichment device called a power valve. This is a vacuum-operated valve which permits a step-like enrichment when preset vacuum levels are reached by the engine. In the Micro-carburetor, a two-step valve is used in which enrichment steps are provided at 6 and 12 inches of Hg manifold vacuum. The power valve is used during acceleration to maintain fuel enrichment beyond the short duration of the accelerator pump.

C. INSTALLATION PROCEDURE

The Micro-carburetor prototype tested by JPL is designed as a retro-fit item for the Chevrolet 350 CID-2V engine. It is well suited for installation by the home mechanic. The procedure for removing the original Rochester carburetor and replacing it with the Micro-carburetor is detailed below:

(1) Remove the air cleaner and disconnect the hoses to the PCV and thermal sensor.
(2) Disconnect the hoses from the carburetor, including EGR, ported spark, cannister purge, and EFE lines.
(3) Disconnect and temporarily cap the fuel line to prevent spillage.
(4) Disconnect the throttle linkage and its return spring.
(5) Disconnect the choke heater wire and unbolt the Rochester carburetor. Remove the stock carburetor and the flange gasket.
(6) Carefully clean the intake manifold flange.
(7) Place the Micro-carburetor and its flange gasket on the manifold. Install the flange bolts and tighten evenly with the special Allen wrench supplied.
(8) Connect the throttle linkage and return spring. Operate linkage from driver's seat to check for correct alignment.
(9) Reconnect the vacuum lines to the appropriately-marked nipples on the Micro-carburetor.
(10) Replace the original fuel line with the one supplied. Bleed and reconnect the fuel line.
(11) Reconnect choke heater wire. If none was supplied in the vehicle, connect the new Micro-carburetor choke heater wire from the distributor input (12 V) to the choke heater element.
(12) Start engine and check for fuel or vacuum leaks.
(13) Install the Micro-carburetor air cleaner with the base flange gasket supplied.
(14) Reconnect the appropriate hoses to the air cleaner.

SECTION III

ENGINE DYNAMOMETER TESTS

A. ENGINE DYNAMOMETER TESTING

Engine dynamometer tests were conducted to compare steady-state performance of the Micro-carburetor to that of a stock baseline carburetor. The objective of the tests was to determine the effects of Micro-carburetor operation on brake specific fuel consumption, thermal efficiency, exhaust emissions, and cylinder-to-cylinder mixture distribution. The steady-state speed/load conditions of the test series are given in Figure 3-1. These points were selected because they represent conditions which frequently appear for the chosen vehicle while performing the Federal Test Procedure (FTP), urban driving cycle, that is mandated for all new vehicles by the EPA.

A Chevrolet 350-2V engine was used for testing. As one of the most common engines in America, this V8 engine was chosen as an appropriate test bed for a potential aftermarket carburetor. Before it was tested, the operating condition of the engine was completely checked. Authenticity to the 1975 49-state configuration was confirmed. All major engine parts were rechecked against manufacturer's blueprint tolerances. When the engine was re-assembled, special care was taken to ensure the originality of all emissions-control devices. The significant emissions devices include; (1) exhaust gas recirculation (EGR), (2) positive crankcase ventilation (PCV), (3) an oxidation catalyst, and (4) early fuel evaporation (EFE) which is a temperature-sensitive vacuum switch operating a heat-riser valve. The fuel-vapor recovery system, which collects evaporated fuel from the carburetor float bowl, was not used because the prototype Micro-carburetor had no external bowl vent.

The stock Rochester 2 bbl carburetor, used as the baseline, was certified by Rochester Products to be representative of those included on the engine as original equipment. The baseline carburetor performed adequately throughout testing and no adjustments of any kind were required. Similarly, after some final adjustments by the Micro Carburetor Corporation, the Micro-carburetor also performed well and required no additional corrections. Through the entire test sequence, no attempt was made to alter the engine. The carburetors were exchanged on the engine, with the vacuum and fuel lines connected to the appropriate ports. Fuel to the carburetor was supplied and measured by the JPL fuel delivery system, shown in Figure 3-2. Indolene Clear gasoline was provided at 6 psig to the carburetor inlet (Ref. 2).

It was recognized during the tests that each carburetor provides its own spark advance strategy. The Rochester has a ported signal for vacuum spark advance that differs from the Micro-carburetor's direct manifold vacuum spark advance. For this reason, the Rochester was tested twice - once with its own spark advance and once with advance equal to that of the Micro-carburetor. In this way, performance differences associated with spark advance could be separated from other operational differences.

There were two exhaust systems used (Ref. 2). The stock exhaust manifolds and muffler, shown schematically in Figure 3-3, were used for sampling the

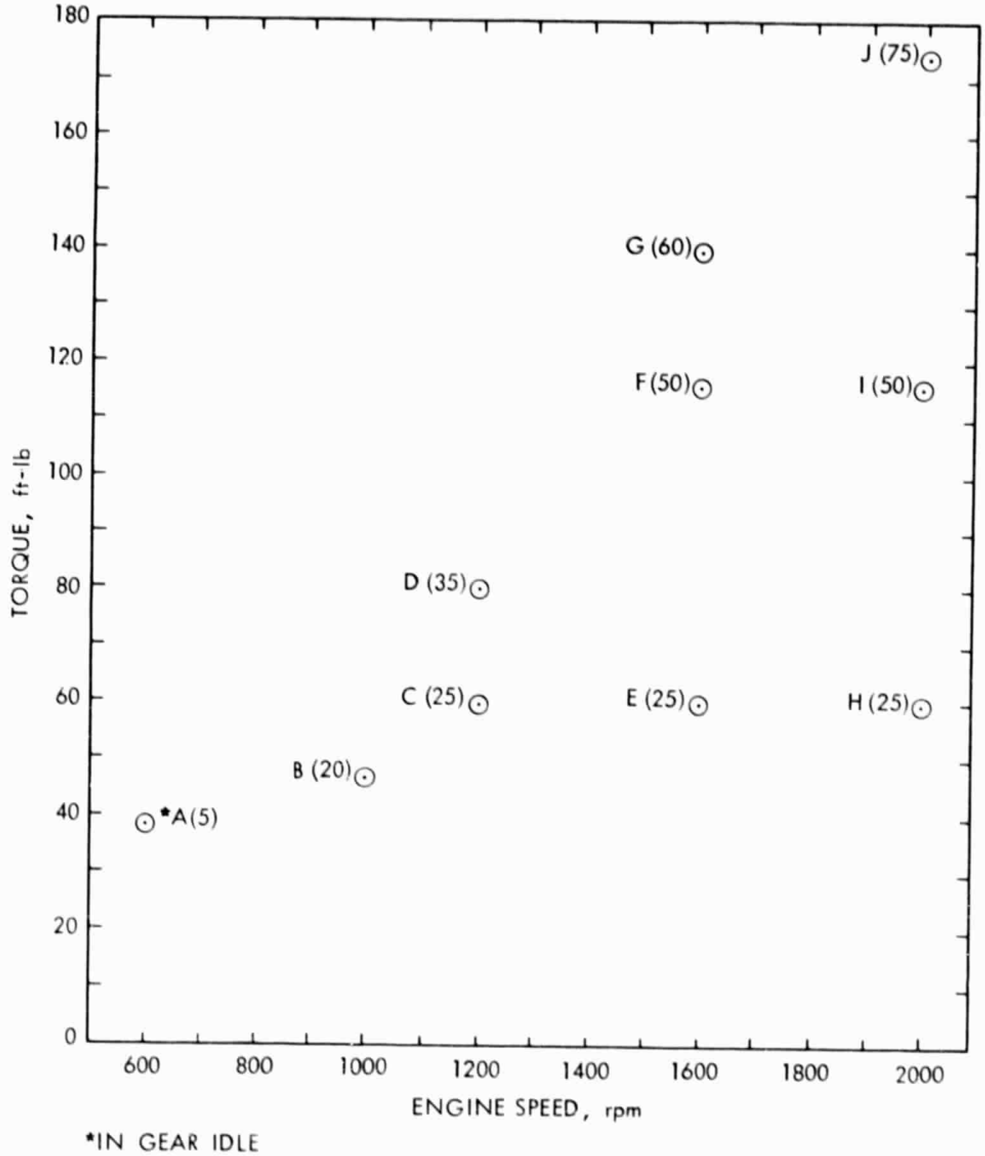


Figure 3-1. Constant Speed/Load Test Points, ft-lb. Brake Mean Effective Pressure (psi) in Parentheses

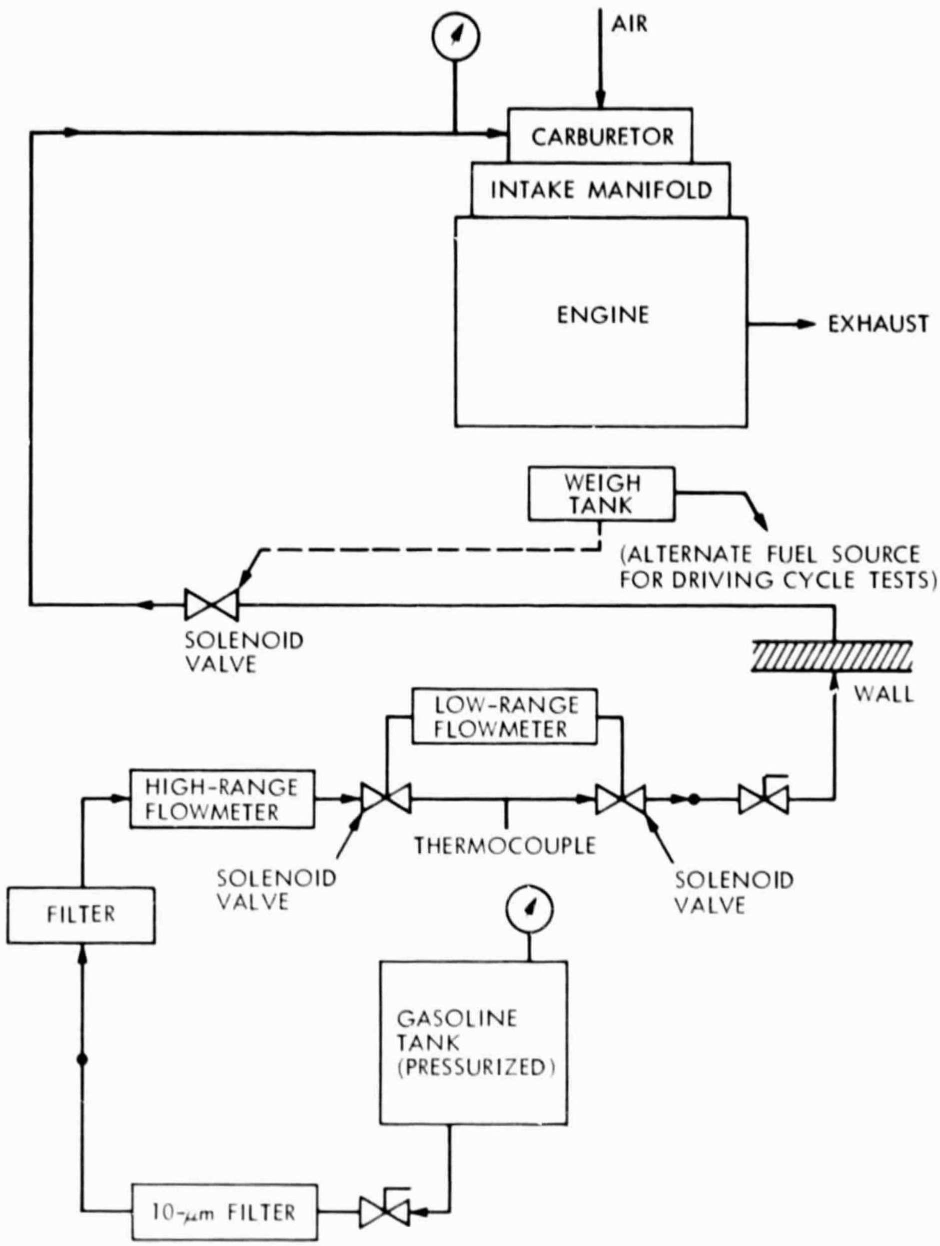


Figure 3-2. Dynamometer Fuel Delivery System

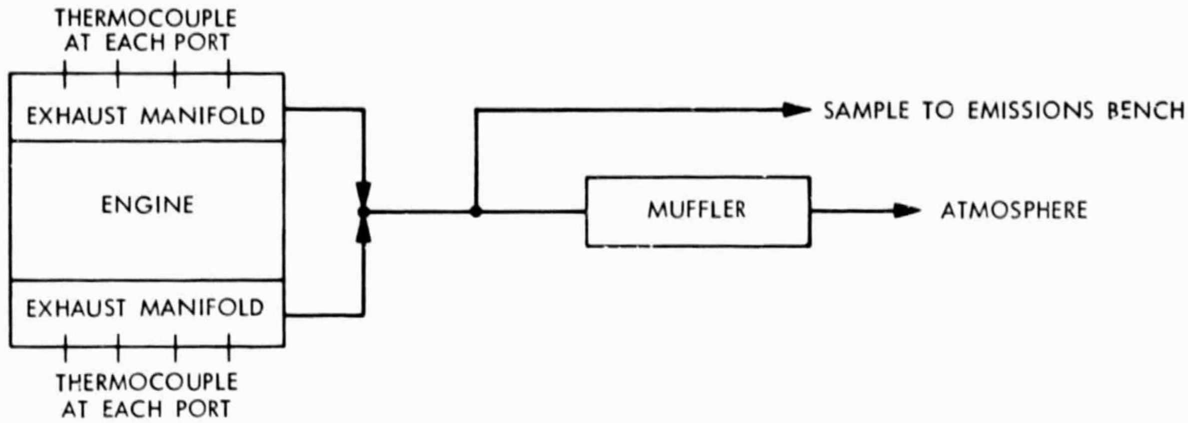


Figure 3-3. Engine Dynamometer Exhaust Plumbing - Aggregate Emissions Sampling

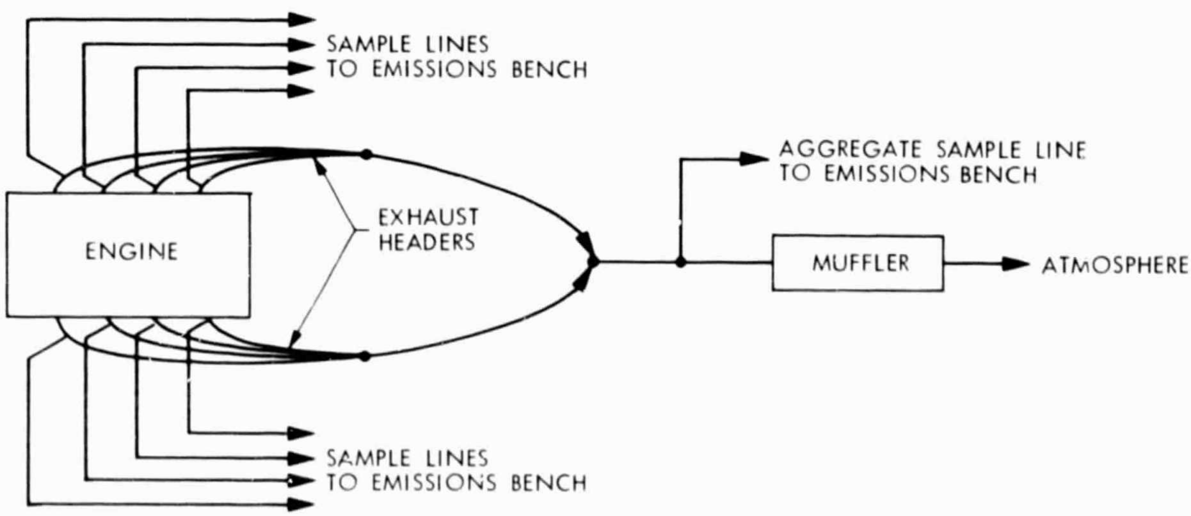


Figure 3-4. Engine Dynamometer Exhaust Plumbing - Distribution Tests

common emissions from all eight cylinders. After the aggregate exhaust sampling was completed for both carburetors, header-type exhaust manifolds were installed. The header-type exhaust manifolds were used to isolate each cylinder's exhaust products. Each cylinder's emissions were sampled from individual probes near the exhaust ports in the header, as shown in Figure 3-4. Aggregate exhaust samples were taken downstream of the header collectors before and after the distribution tests to ensure that engine operating conditions had remained stable. This sample was taken downstream of the headers after the exhaust products from all eight cylinders were well mixed. This was done to provide insight into any possible effect of using the headers instead of the stock exhaust manifolds for the distribution tests.

The water brake dynamometer system is shown in Figure 3-5. The dynamometer calibration was checked before, during, and after the test sequence and was found to be within rated accuracy. The engine is shown on the test stand in Figure 3-6.

B. ENGINE DYNAMOMETER TEST RESULTS

A series of engine dynamometer tests were conducted to compare the performance of a 1975 350 CID stock engine equipped with a Rochester carburetor to that of the same engine equipped with the Micro-carburetor. Figure 3-7 gives the comparative fuel flows at all test points. In most cases, the Micro-carburetor delivered from 2% to 12.6% less fuel flow at similar speed-load points. The Micro-carburetor provided a fuel savings ranging from 3% to 5% at moderate loads to over 12% at higher loads and idle. Past idle, the fuel savings tended to increase with load, as long as the power enrichment conditions were not reached.

Brake specific fuel consumption (bsfc) levels are given in Figure 3-8. The Micro-carburetor provided equal or better bsfc at every test point. At point I (2000 rpm/116 ft-lb) the Rochester's mechanical power valve was closed. The Micro-carburetor's power valve opened, causing the Micro-carburetor to run richer than the baseline. At point I, equal bsfc was achieved despite the Micro-carburetor's higher fuel flow. At the other points, bsfc improvements ranged from 2.6% to 17%. The largest bsfc improvements occurred at idle and high power - 15% and 17%, respectively. At most moderate speeds and loads, the Micro-carburetor yielded bsfc reductions of 2.6% to 6.4%. These bsfc improvements generally increased with higher load.

The Micro-carburetor tended to increase the thermal efficiency (see Appendix D) at every point tested, as shown in Figure 3-9. The largest improvements in the utilization of the fuel's energy occurred at the high-load point J (2000 rpm/174 ft-lb) and at the in-gear idle point A (600 rpm/38 ft-lb). Somewhat smaller improvements were present at the mid-load test conditions. Points D (1200 rpm/80 ft-lb), E (1600 rpm/58 ft-lb), F (1600 rpm/80 ft-lb), G (1600 rpm/116 ft-lb), H (2000 rpm/58 ft-lb), and I (2000 rpm/116 ft-lb) gave thermal efficiency improvements ranging from 0.4% at point E to 5.9% at point F.

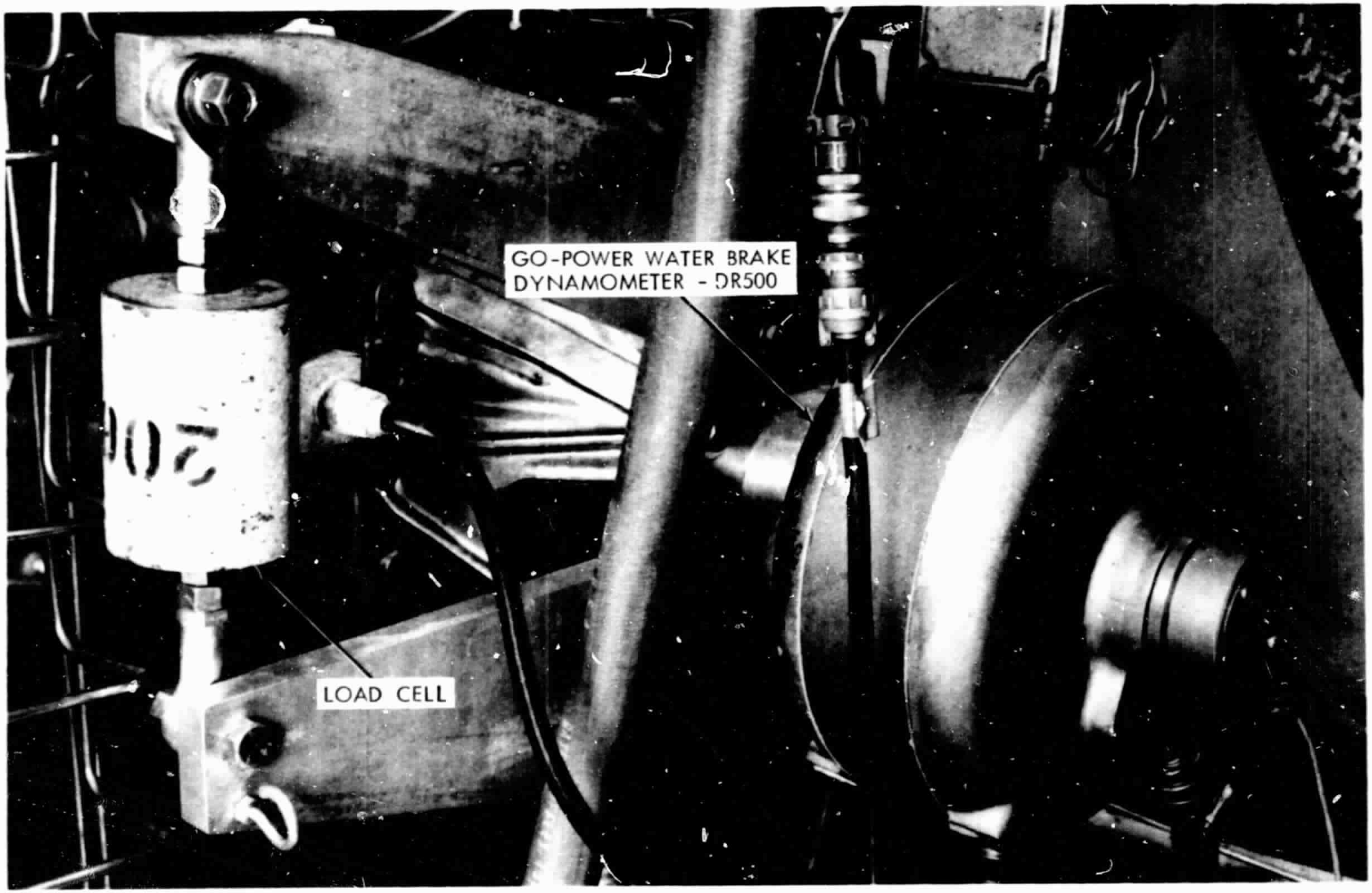


Figure 3-5. Water Brake Dynamometer

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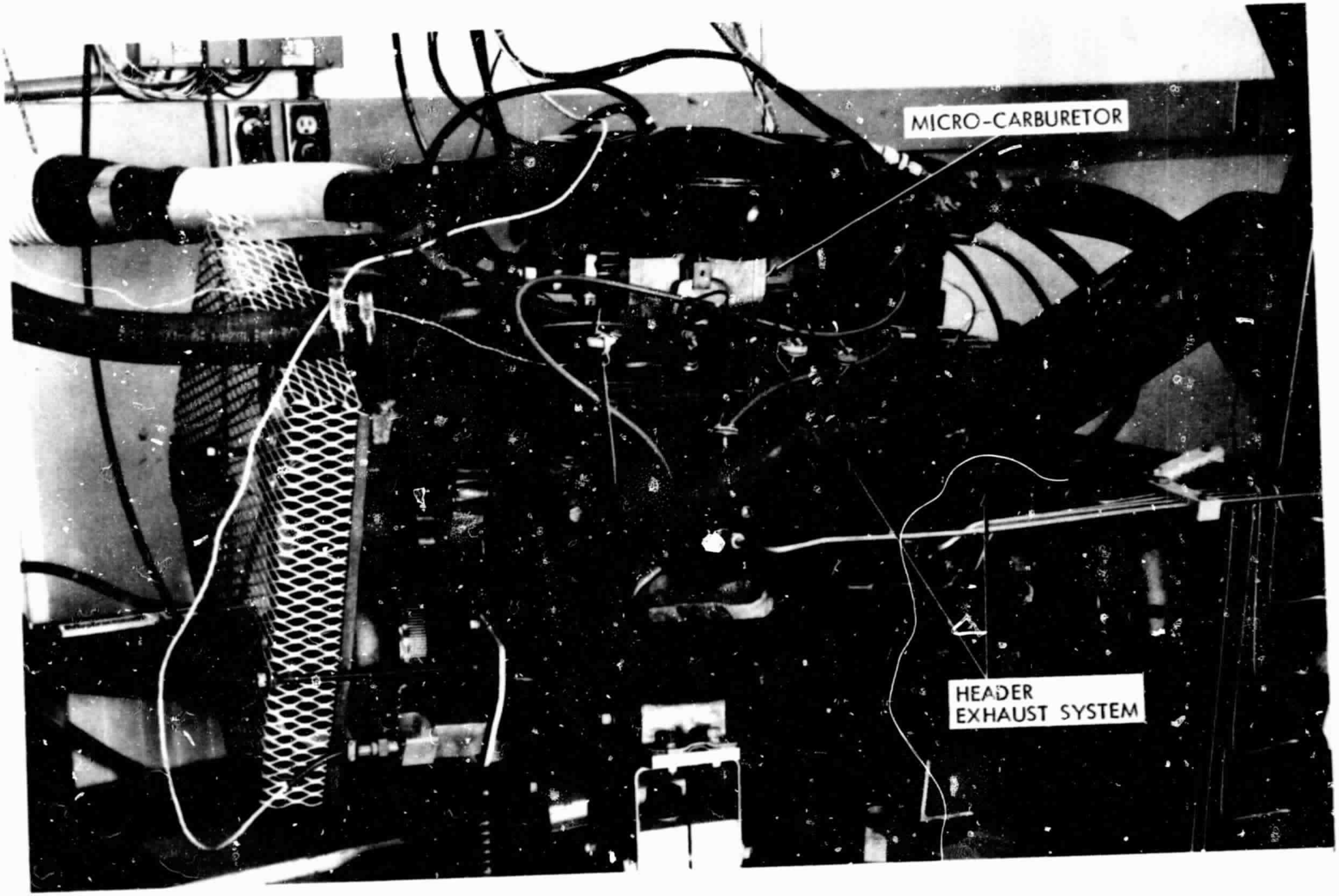

Figure 3-6. Engine on Dynamometer Test Stand

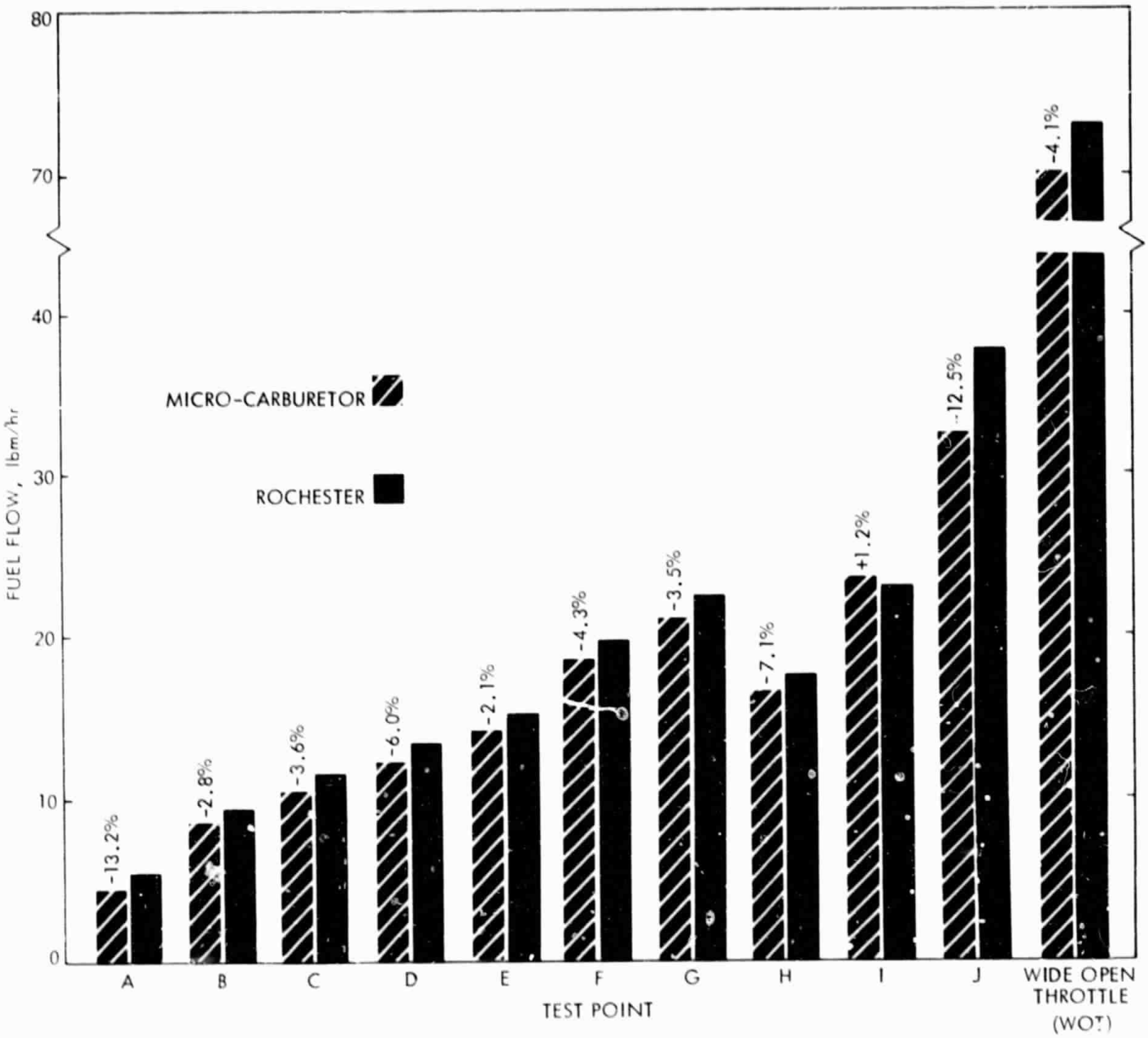

Figure 3-7. Fuel Flow, lbm/hr

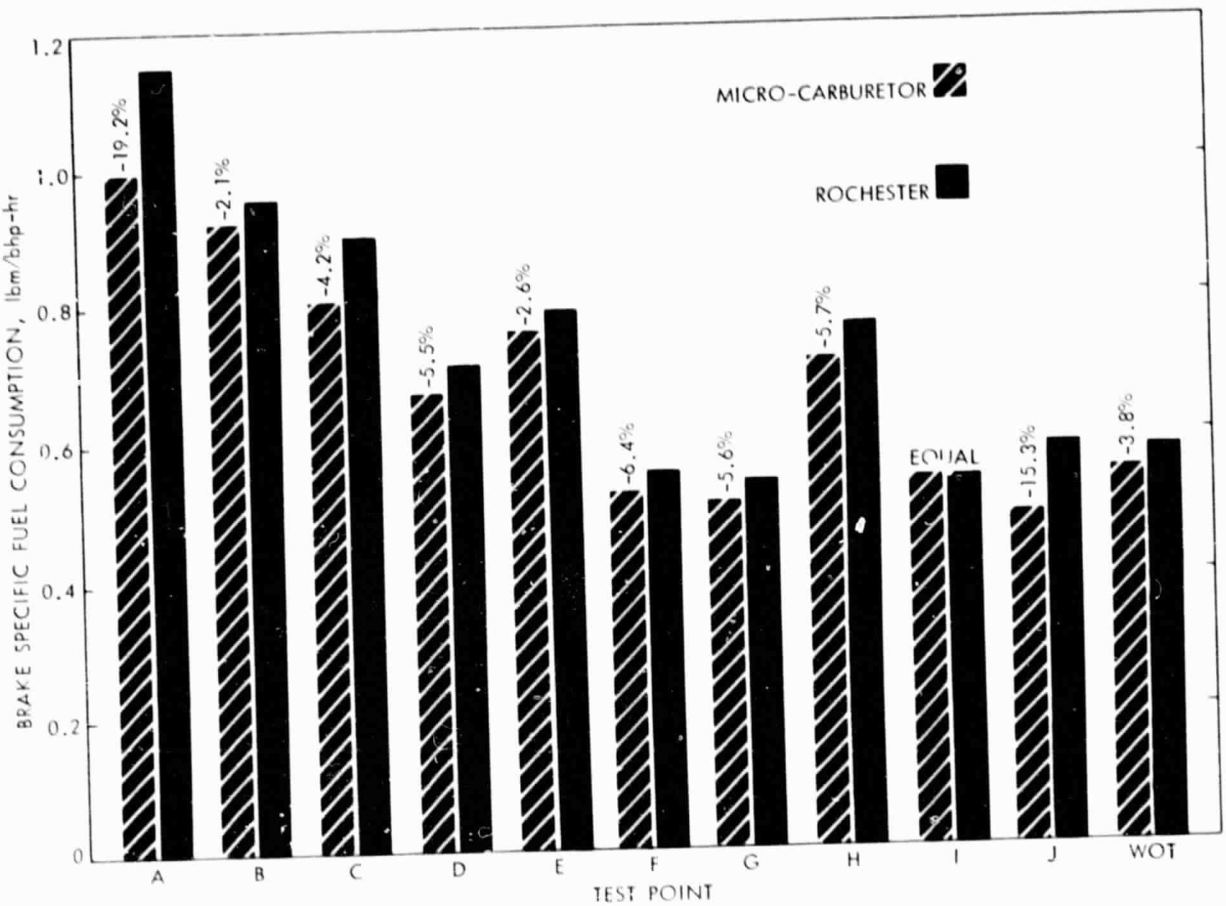

Figure 3-8. Brake Specific Fuel Consumption, lbm/bhp-hr

At point I, the Micro-carburetor power valve was open, and the thermal efficiency reached a test-high value of 35.1%. This was one of the conditions in which the Micro-carburetor was richer than the stock Rochester, as shown in Table 3-1. Enriched slightly beyond stoichiometric at points G, I, and J, the Micro-carburetor demonstrated consistently high thermal efficiencies.

The low-load points tested were B (1000 rpm/46.4 ft-lb) and C (1200 rpm/58 ft-lb). The thermal efficiencies showed a small improvement at these points, as seen in Figure 3-9. At point B, the Micro-carburetor delivered the leanest equivalence ratio observed, $\phi = 0.813$ (see Table 3-1). Here, the aggregate mixture was extremely lean when compared to the Rochester's equivalence ratio of $\phi = 0.975$. The thermal efficiencies of the two carburetors at point B show near-equal values despite the differences in equivalence ratio.

The last column in Figure 3-9 indicates that at 3000 rpm, WOT, a thermal efficiency improvement of 4.4% was achieved with the Micro-carburetor. The aggregate mixture strength of $\phi = 1.180$ was richer than the baseline Rochester at $\phi = 1.146$. The maximum brake horsepower (bhp) of the Micro-carburetor was

Table 3-1. Aggregate Equivalence Ratio Comparison Steady-State Engine Tests

TEST POINT	BASELINE	MICRO-CARBURETOR	DIFFERENCE
A	.905	.826	.079 L
B	.971	.813	.158 L
C	.943	.870	.073 L
D	.928	.843	.085 L
E	.905	.857	.048 L
F	.983	.981	.002 L
G	.996	1.008	.012 R
H	.934	.921	.013 L
I	.983	1.025	.042 R
J	1.199	1.040	.159 L
WOT	1.146	1.180	.034 R

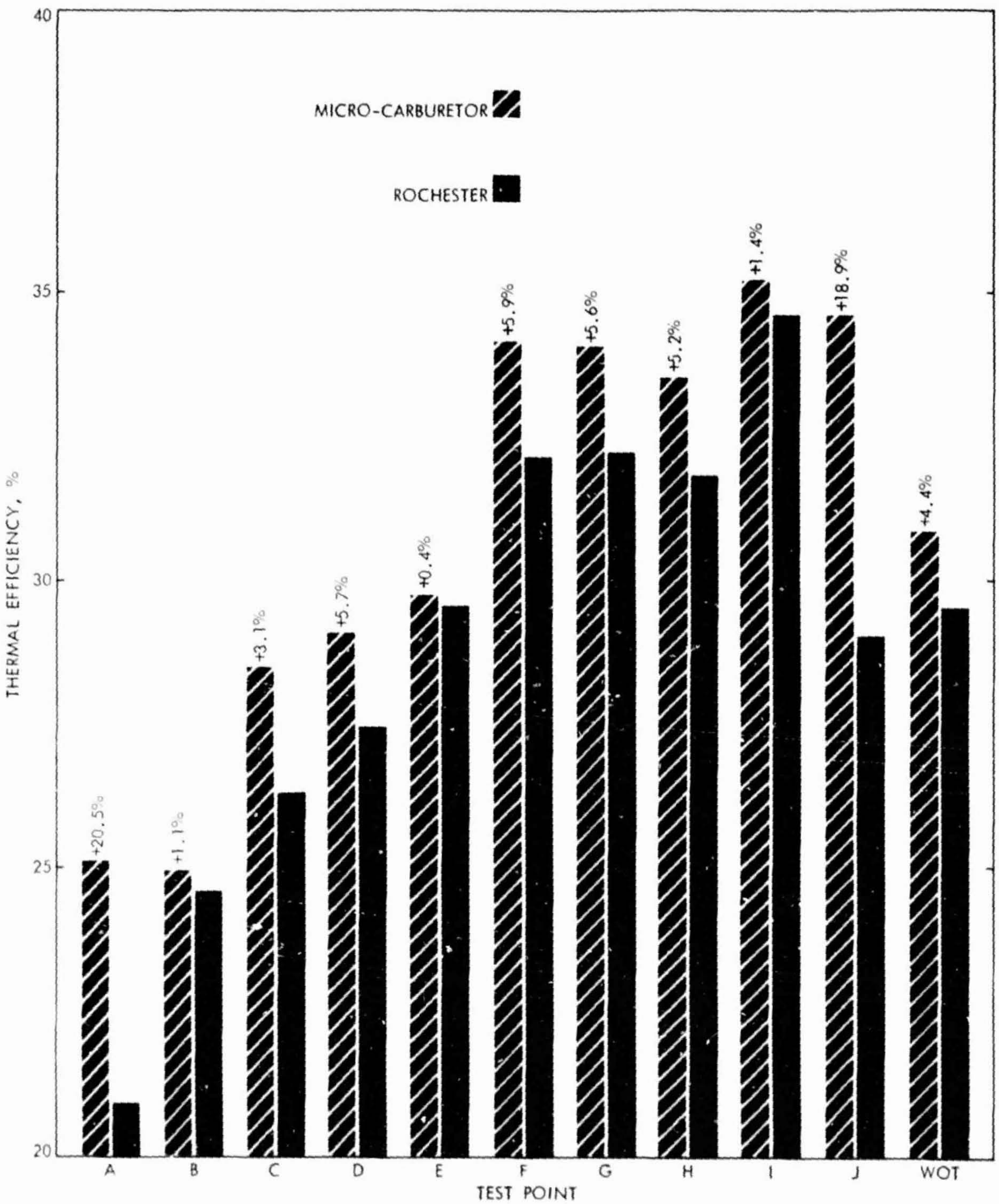

Figure 3-9. Thermal Efficiency

almost equal to the Rochester, declining slightly from 127.3 to 126.7 bhp. The thermal efficiency improvement did not result in more power due to the loss in volumetric efficiency (see Appexdix E) (shown in Figure 3-10). At 3000 rpm, WOT, the Micro-carburetor exhibited a 5.1% loss in its ability to fill the cylinders. This reduction in charging efficiency countered the gain in thermal efficiency, but a bsfc improvement of 3.8% was noted.

At most other test points, the volumetric efficiency was reduced for the Micro-carburetor as a result of increased engine throttling. Because the Micro-carburetor tended to increase thermal efficiency, more throttling was generally required to maintain the speed-load test points.

Interestingly, at points B, C, D, and E, the volumetric efficiency was higher for the Micro-carburetor. At these points the Micro-carburetor was less throttled than the Rochester. Thermal efficiency and bsfc improvements were also present at these points. This was due to the Micro-carburetor's lean calibration in this operating regime. Points B through D had the greatest differences in equivalence ratios between the two carburetors. Table 3-1 shows that the Micro-carburetor mixture strengths ranged from $\phi = 0.813$ to $\phi = 0.870$ for points B, C, D, and E.

The results obtained in the cylinder-to-cylinder distribution tests are given in Figures 3-11a-i and 3-12. Figures 3-11a through 3-11i give the equivalence ratio of each cylinder (Ref. 3) and also the excursion from the aggregate equivalence ratio. (Distribution tests at idle were not performed because the water-brake dynamometer could not provide even enough control at idle loads. This minor deficiency in dynamometer control caused an average variance in bhp of 1.74% between tests.) Only points B and D showed a degradation of charge distribution. All other data points achieved improved mixture distribution control (see Figure 3-12). The variance of the cylinder-to-cylinder equivalence ratio is given. This is a measure of the amount of the cylinder-to-cylinder equivalence ratio excursion from the aggregate equivalence ratio. In most cases the distribution improvements were dramatic. For the extremely lean point B, the distribution (Figure 3-11a) shows that three ultra-lean excursions occurred in cylinders 1, 4, and 7. These cylinders showed measured equivalence ratios less than $\phi = 0.790$.

General engine dynamometer test results are located in Appendix B, Tables B-1 through B-5. Cylinder-to-cylinder emissions tests results are given in Appendix B, Figures B-1 through B-10.

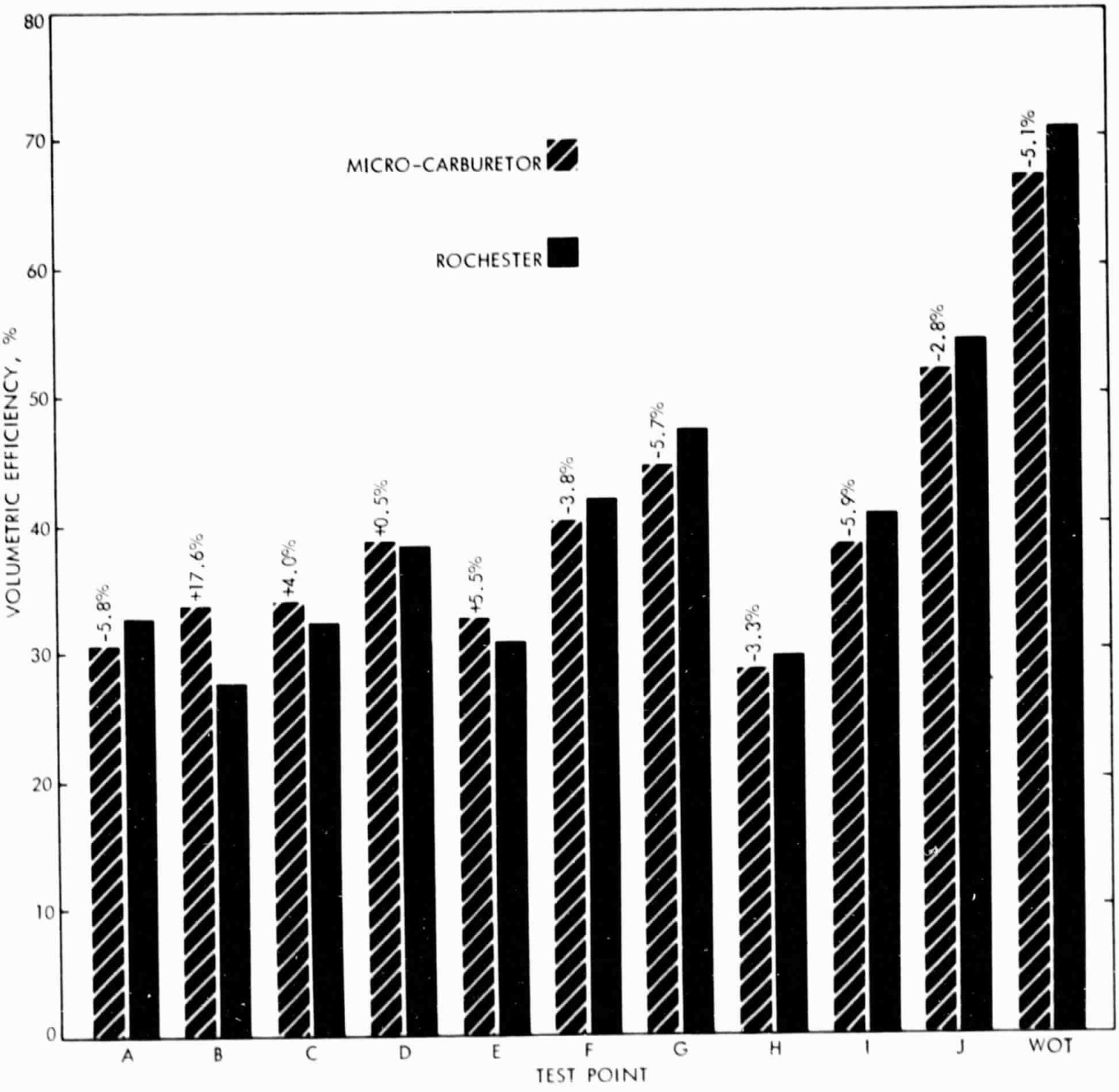

Figure 3-10. Volumetric Efficiency

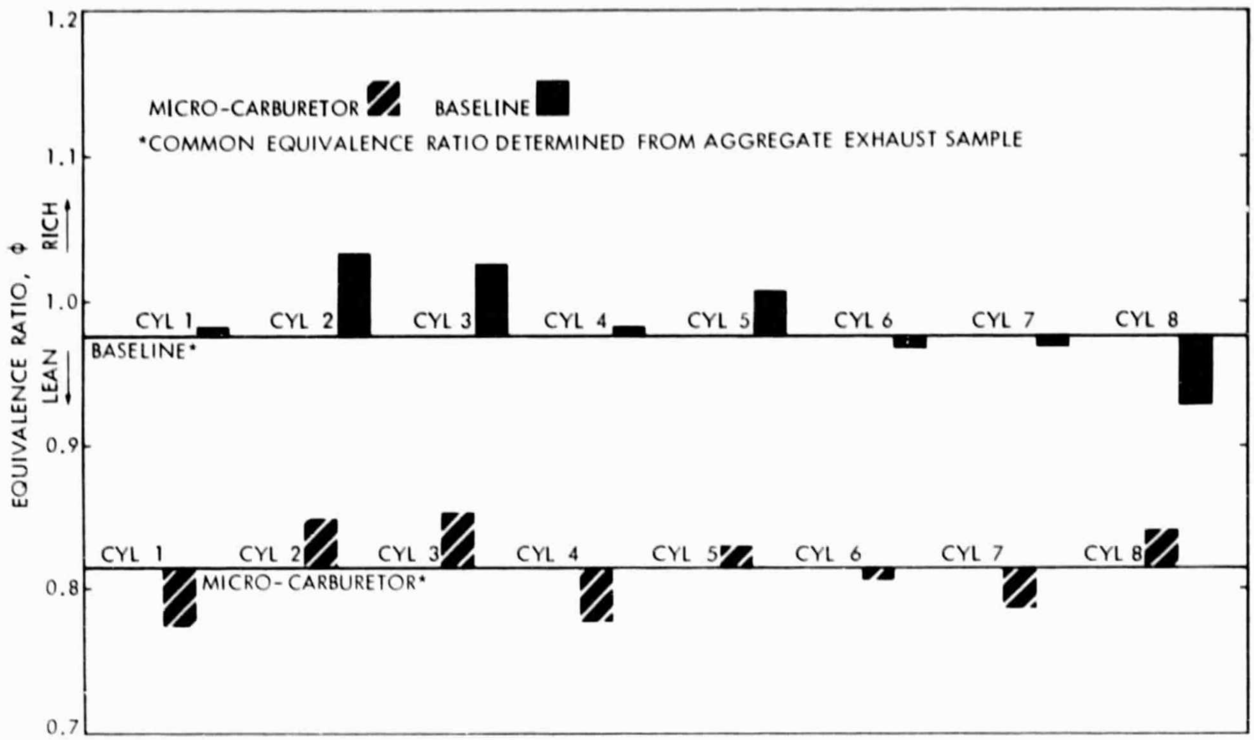

Figure 3-11a. Cylinder-to-Cylinder Equivalence Ratio Distribution, Point B

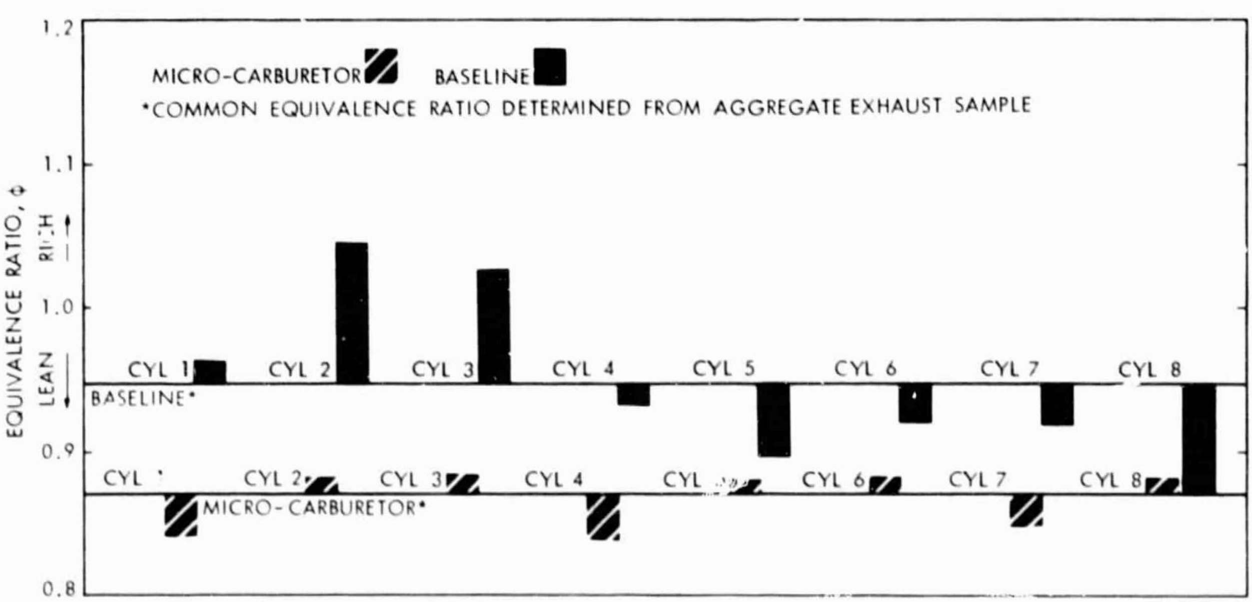

Figure 3-11b. Cylinder-to-Cylinder Equivalence Ratio Distribution, Point C

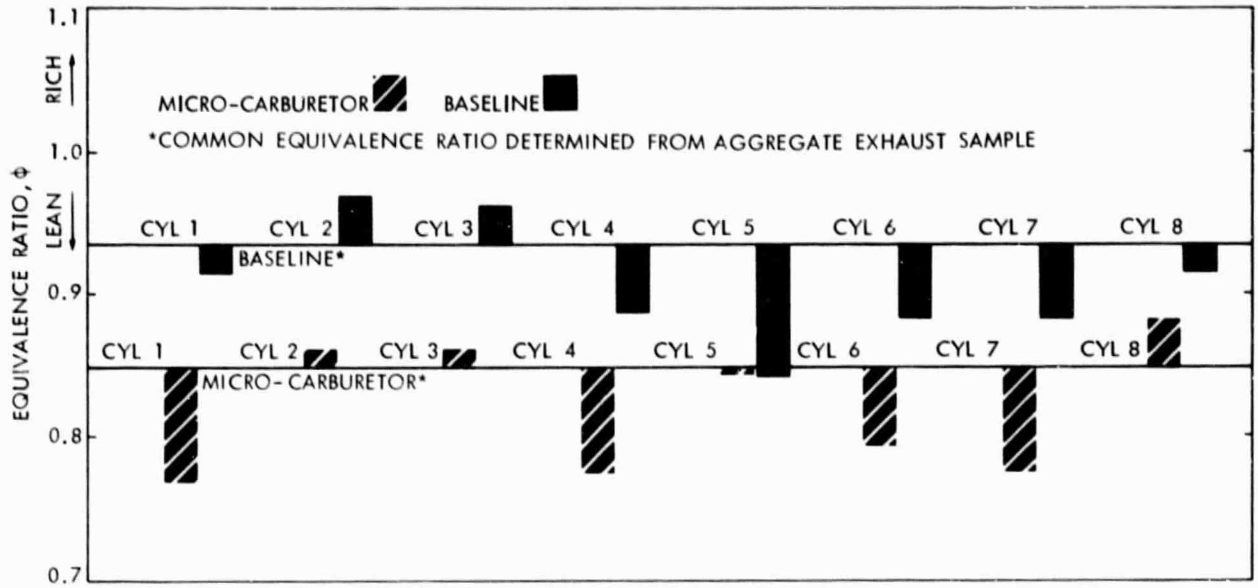

Figure 3-11c. Cylinder-to-Cylinder Equivalence Ratio Distribution, Point D

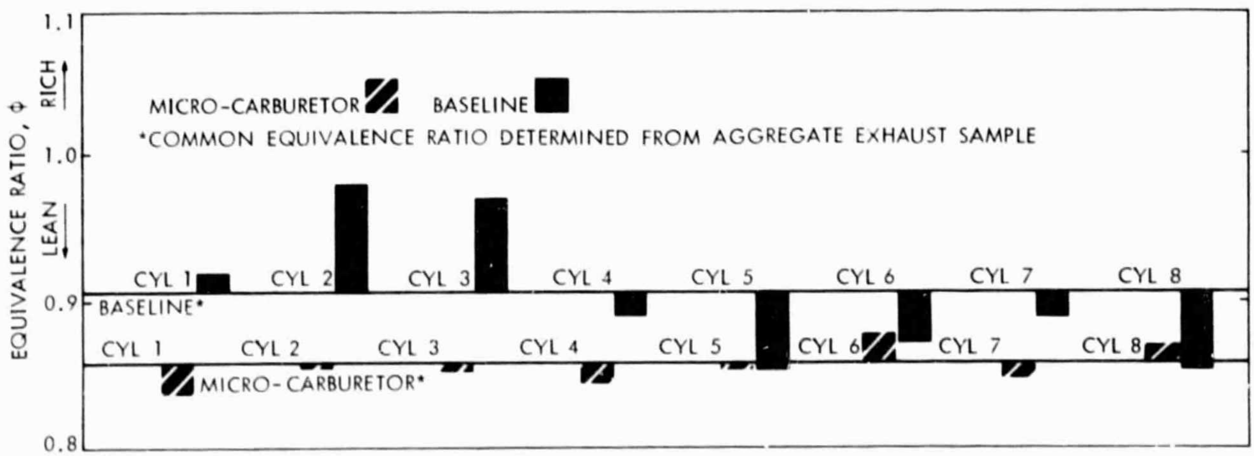

Figure 3-11d. Cylinder-to-Cylinder Equivalence Ratio Distribution, Point E

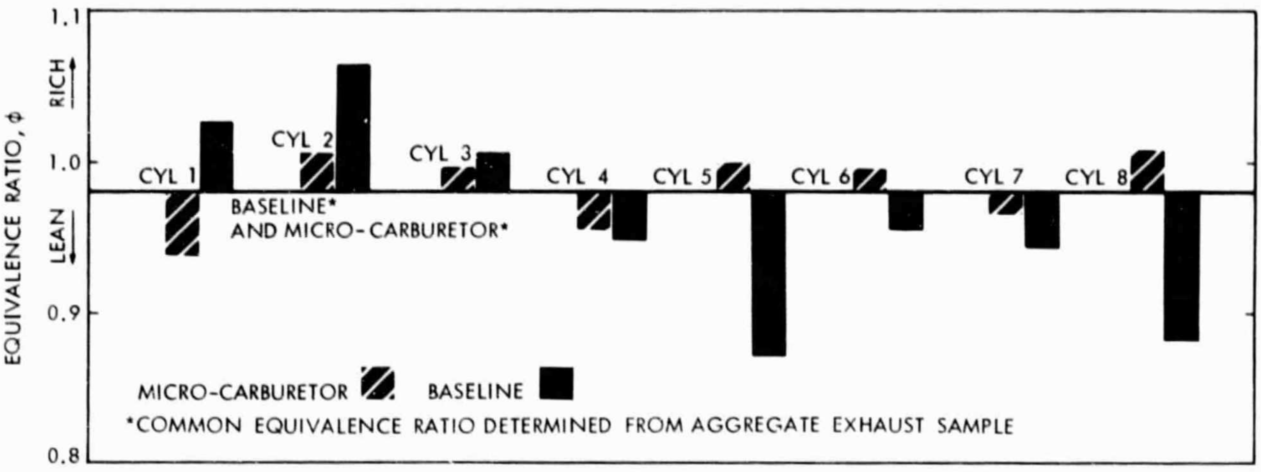

Figure 3-11e. **Cylinder-to-Cylinder Equivalence Ratio Distribution, Point F**

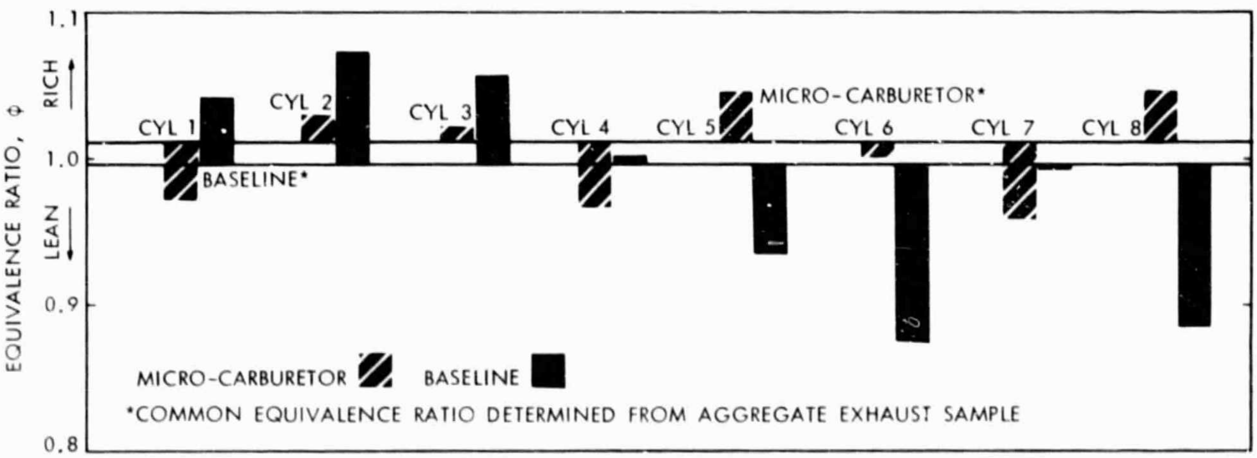

Figure 3-11f. **Cylinder-to-Cylinder Equivalence Ratio Distribution, Point G**

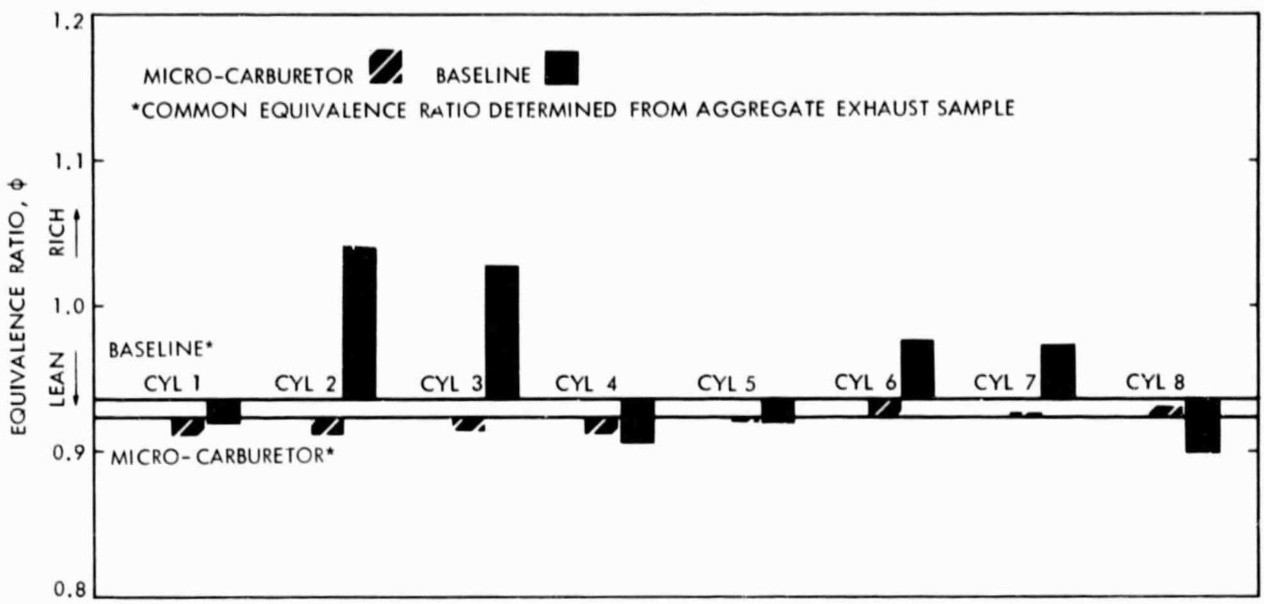

Figure 3-11g. Cylinder-to-Cylinder Equivalence Ratio Distribution, Point H

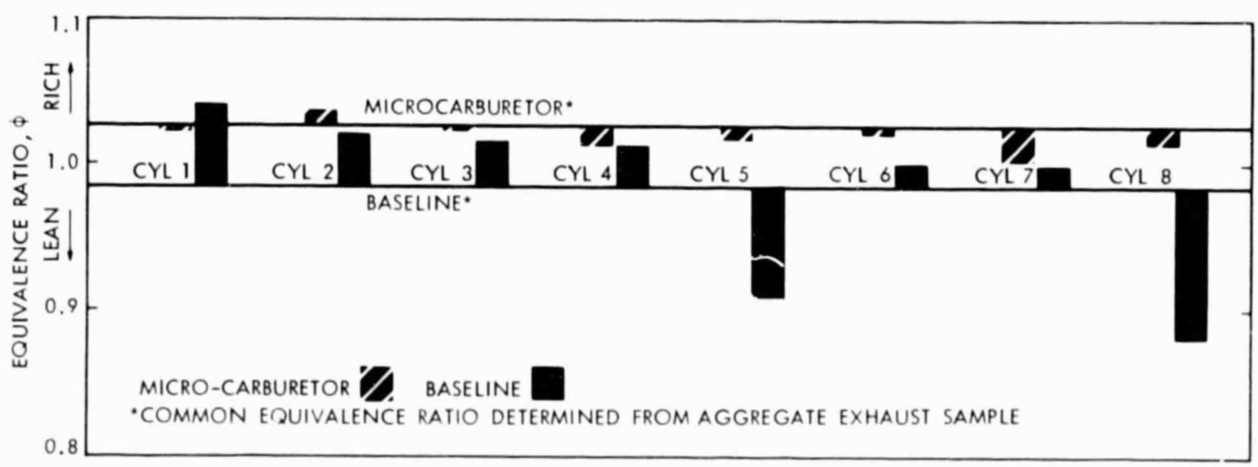

Figure 3-11h. Cylinder-to-Cylinder Equivalence Ratio Distribution, Point I

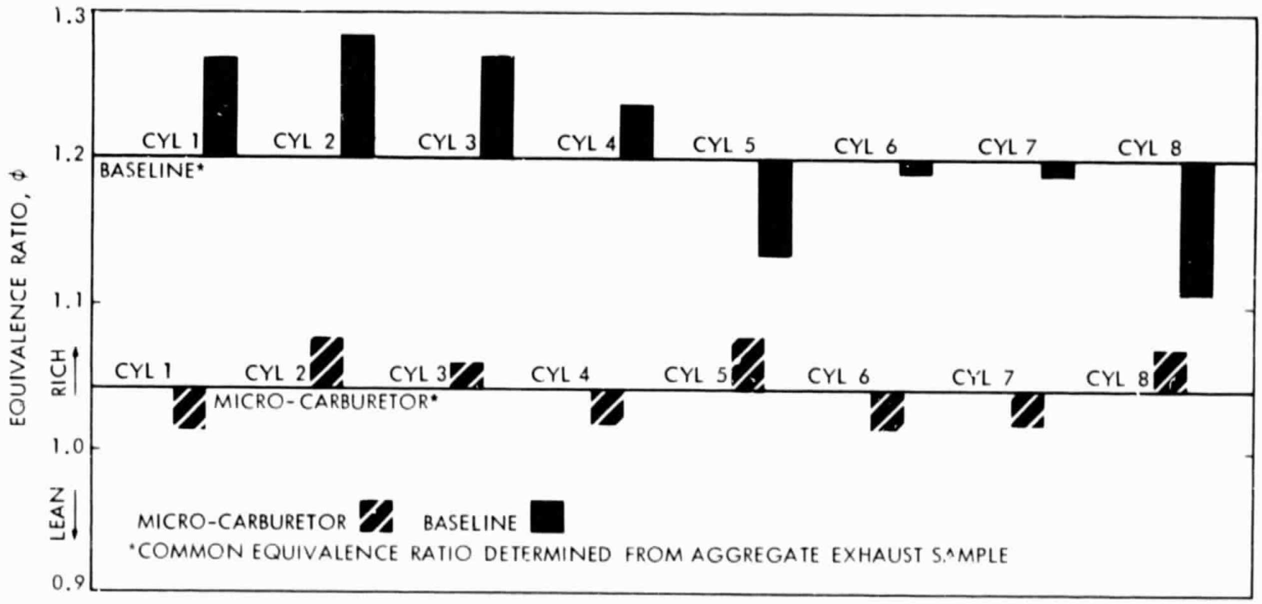

Figure 3-11i. Cylinder-to-Cylinder Equivalence Ratio Distribution, Point J

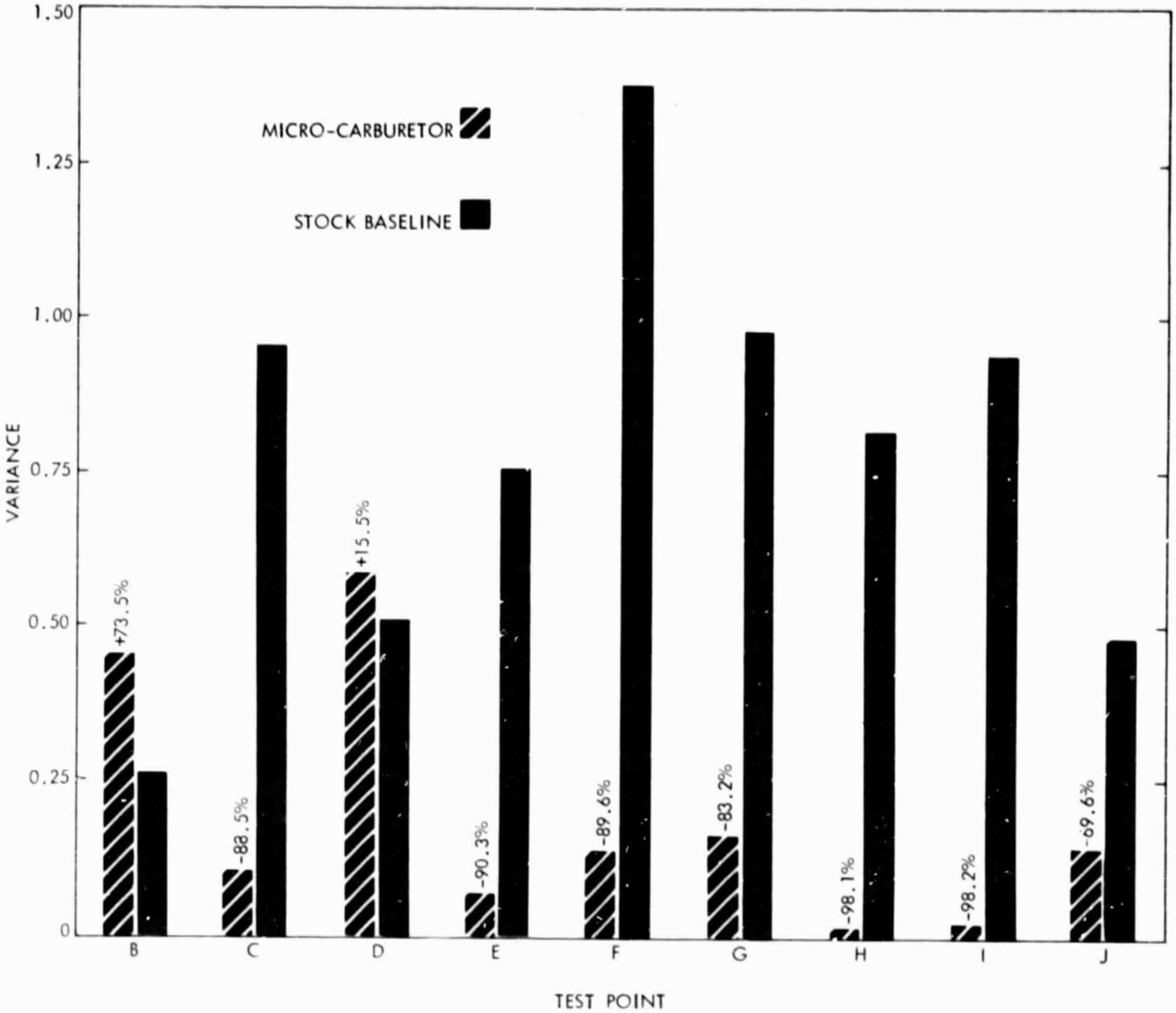

Figure 3-12. Cylinder-to-Cylinder Equivalence Ratio Distribution Variance

SECTION IV

CHASSIS DYNAMOMETER DRIVING CYCLE TESTS

A. CHASSIS DYNAMOMETER TESTING

A series of chassis dynamometer tests were performed, conforming to the 1975 FTP, urban driving cycle. The purpose of the tests was to determine the effects of Micro-carburetor operation on vehicle fuel economy and emissions. With the test engine installed in a Chevrolet Impala, the urban cycles were performed first with the Rochester carburetor and then with the Micro-carburetor. As in engine dynamometer tests, all emissions hardware was verified. In addition, a new exhaust catalyst was fitted.

Inertia weights corresponding to a 4000-lb vehicle were set on the Clayton twin-roll chassis dynamometer. The vehicle was equipped with a Turbo Hydramatic 350 automatic transmission, driving a 2.73 rear axle ratio with G78-15 tires and power brakes. The power brakes later proved to be a difficulty because the Micro-carburetor had no power-brake vacuum supply fitting. This problem was corrected by relocating the brake vacuum line about 5-cm lower, into the manifold plenum. Subsequent testing showed no measurable differences from the stock location used with the Rochester carburetor.

The vehicle fuel used for chassis dynamometer tests was also Indolene Clear. Fuel consumption was measured gravimetrically with a weigh tank and was also calculated using the carbon balance technique from the Federal Register (Ref. 4). These techniques agreed within 2.5%.

Exhaust emissions were available in two forms. The federally-prescribed constant volume sample (CVS) collects three diluted bags of exhaust emissions during the FTP. In addition, on-line emissions instruments provided real-time recordings of CO, CO_2, HC, O_2, and NO_x. All data given are averages of at least 3 FTP cycles.

B. CHASSIS DYNAMOMETER TEST RESULTS

The chassis dynamometer tests were evaluated on a cold-start and a hot-start basis. That is, the cold-transient portion (bag 1) was combined with the warm-stabilized portion (bag 2) and the hot-transient restart portion (bag 3) to form a cold-start FTP. For the hot-start test, only bags 2 and 3 were considered.

The urban driving cycle tests with the Rochester carburetor were conducted with the ported spark (baseline) and again with direct manifold vacuum spark advance. The difference between these two spark advance configurations occured at idle and off-idle. The onset of full manifold vacuum spark advance was delayed until the Rochester's throttle plate swept past the port, thereby subjecting the port to intake manifold vacuum. With ported spark advance, there was only 6° of spark advance at idle. With the manifold vacuum advance, there was 23.3° of advance at idle. The difference between the two configurations rapidly disappeared off-idle.

The test results given in Table 4-1 show the fuel economy and emissions effects of the Micro-carburetor compared with the stock Rochester carburetor. A 13.2% improvement in fuel economy was realized with the Micro-carburetor, along with a significant increase in CO and HC emissions. Table 4-2 provides a comparison of the Micro-carburetor and the Rochester, both using direct manifold vacuum spark advance. With equal spark advances, the fuel economy benefit of the Micro-carburetor was 9.7%. The emissions penalties were also reduced. Although all emissions levels remained within specified legal limits, it is not known whether this would still be the case after 50,000 miles of catalyst deterioration.

Steady-state fuel economy at highway speed was calculated during the FTP urban cycles. The high speed cruise portion of bag 3 was utilized for this purpose. A 30 second segment of this cruise, approximately 200 seconds into bag 3, was isolated. Here, vehicle speed was consistently 55 mph within (0.4 mph). The baseline Rochester ran 17.88 mpg at 55 mpg while the Micro-carburetor ran 19.20 mpg. This reflects an advantage of 1.32 mpg or 7.4% for the Micro-carburetor at 55 mph.

It was observed during the FTP urban cycles that an abnormally high amount of exhaust emissions were generated in the cold-start (first bag) portion of the Micro-carburetor test. This suggested that a less than optimum choke strategy had been adopted. Table 4-3 presents data from the hot-start portion of the FTP, bags 2 and 3. This comparison of the Micro-carburetor and the Rochester was done for two reasons. The Rochester with ported spark showed consistently low emissions levels, which formed an excellent set of emissions baselines. Secondly, although the choke was an essential part of the carburetor, the main functions of air/fuel metering were divorced from the choke functions.

Table 4-3 shows a 16.9% increase in fuel economy for the Micro-carburetor. A 37.3% decrease in CO emissions was also observed, while NO_x remained low and HC nearly doubled. The Rochester carburetor produced 0.363 gm/mi HC - nearly half of the already low Micro-carburetor level. It was observed from the strip-chart recordings that during the hot-start tests, the Micro-carburetor generated a considerable portion of the HC emissions during decelerations. The increase in fuel economy and improvement in CO emissions tend to support claims of improved mixture preparation for the Micro-carburetor. The decrease in CO emissions indicates that some rich cylinders in the engine had become leaner. The near-equal NO_x production suggests that combustion temperatures were not hotter than the baseline values.

The results of hot-start tests with direct manifold vacuum spark advance are shown in Table 4-4. The Micro-carburetor produced a 46.8% reduction in CO emissions, while HC and NO_x remained nearly equal to the modified-stock configuration. The increased spark advance with the Rochester carburetor increased its emissions levels somewhat. The Micro-carburetor's emissions represent a clear improvement over the Rochester's, based on equal spark advance. The fuel economy improvement was 18.1% - the largest recorded for the Micro-carburetor.

Table 4-1. FTP Cold Start Results: Micro-Carburetor vs Rochestor with Ported Spark Advance

	URBAN FTP FUEL ECONOMY mpg	HC gm/mi	CO gm/mi	NO_x gm/mi
STOCK BASELINE[a] (PORTED SPARK ADVANCE)	12.95	0.537	5.99	2.40
MICRO-CARBURETOR (MANIFOLD SPARK ADVANCE)	14.65	1.01	10.15	2.52
% CHANGE, COMPARED WITH STOCK	+13.2%	+88.1%	+69.4%	+5.0%
EPA STANDARD, 1975	N/A	1.5	15.0	3.1

(a) Chevrolet 4000 lb, 350-2V, 350-TH Auto Transmission, 2.73/1 Drive Ratio.

Table 4-2. FTP Cold Start Results: Micro-Carburetor vs Rochestor with Direct Manifold Vacuum Spark Advance

	URBAN FTP FUEL ECONOMY mpg	HC gm/mi	CO gm/mi	NO_x gm/mi
STOCK CARBURETOR WITH MANIFOLD SPARK ADVANCE	13.36	0.792	6.47	2.80
MICRO-CARBURETOR (MANIFOLD SPARK ADVANCE)	14.65	1.01	10.15	2.52
% CHANGE, COMPARED WITH STOCK	+9.7%	+27.5%	+56.9%	-9.96%
EPA STANDARD, 1975	N/A	1.5	15.0	3.1

Table 4-3. FTP Hot Start Results: Micro-Carburetor vs Rochestor with Ported Spark Advance

	FUEL ECONOMY mpg	HC gm/mi	CO gm/mi	NO_x gm/mi
STOCK CARBURETOR WITH PORTED SPARK ADVANCE	13.8	0.263	1.83	2.34
MICRO-CARBURETOR (MANIFOLD SPARK ADVANCE)	16.13	0.483	1.15	2.54
% CHANGE, COMPARED WITH STOCK	+16.9%	+93.9%	-37.3%	+5.5%

Table 4-4. FTP Hot Start Results: Micro-Carburetor vs Rochestor with Direct Manifold Vacuum Spark Advance

	FUEL ECONOMY mpg	HC gm/mi	CO gm/mi	NO_x gm/mi
ROCHESTER CARBURETOR (MANIFOLD SPARK ADVANCE)	13.66	0.464	2.16	2.63
MICRO-CARBURETOR (MANIFOLD SPARK ADVANCE)	16.13	0.483	1.15	2.54
% CHANGE, COMPARED WITH STOCK	+18.1%	+4.1%	-46.8%	-3.4%

SECTION V

DRIVEABILITY TESTING

Driveability is a dynamic property of a vehicle. It is an indication of a vehicle's tendency to maintain a steady level of performance response to throttle input commands. The effect of Micro-carburetor operation on vehicle performance response was observed under varied conditions. The tests were representative of U.S. auto industry driveability tests and were performed by engineers experienced in driveability testing. After testing the stock Rochester-equipped vehicle, the Micro-carburetor was installed and the identical test sequence repeated. Generally, at least three data points were taken per test in order to recognize consistency of performance. Fuel for the driveability tests was unleaded pump gasoline.

A. COLD ENGINE DRIVEABILITY TEST RESULTS

The cold engine driveability tests examined how well the car started and drove off after an 18-hour soak at about 50°F ambient temperature. Cranking time was measured, along with the number of stalls. After the startup, spark advance, E.G.R., and intake vacuum readings were taken in neutral and drive gears. Idle quality was rated "satisfactory" or "unsatisfactory." The vehicle was driven away from rest, and vacuum readings were taken again. The driveaway character was also rated "satisfactory" or "unsatisfactory." Fifty feet from the departure point, the car was stopped and engine vacuum readings were taken at in-gear idle. This was followed by another driveaway at a different acceleration vacuum. This acceleration, cruise, brake, and idle pattern continued at 0.2-mile intervals for several miles.

Transient performance response tests were performed subsequent to the cold driveaway tests when the engine was not yet fully warmed. These tests amounted to a series of "throttle tip-ins" from an initial cruise or deceleration. The objective of the transient performance response tests was to observe the sensitivity of the fueling system's operation to varying throttle commands from different initial conditions. A preselected pattern of "throttle tip-ins" was conducted which covered the matrix of possible combinations from low-initial-speed/light-throttle-command to a passing maneuver at high-speed/heavy-throttle-command.

The tabulated results from the cold driveability tests are shown in Appendix F, Tables F-3 through F-7. Throughout the tests, the Rochester carburetor performed flawlessly, delivering consistently adequate engine operation. Against this standard, the Micro-carburetor did well in most major areas. Driveaways beyond 50 feet had near equal quality at similar driveaway vacuums. Idle vacuums and qualities were near equal for the two carburetors, each exhibiting slight roughness. All Rochester drive ratings were satisfactory. All of the Micro-carburetors ratings were satisfactory except for the two listed below.

The Micro-carburetor showed rapid start times but often failed to continue to run. A large number of stalls occurred due to the failure of the fast-idle system to raise engine rpm after startup. It was determined that the idle screw was seated on the fast-idle cam, but that fast idle did not initiate until beyond the 50-ft driveaway point. The only other cold driveability problem on the

Micro-carburetor was the inability to provide vehicle acceleration at or near wide-open throttle (WOT) without a stall. This was believed to be the result of insufficient accelerator pump delivery. It was concluded that while the throttle opened wide to admit air, the fuel delivery lagged sufficiently far behind to starve the engine.

B. HOT ENGINE DRIVEABILITY TEST RESULTS

The hot engine driveability tests provided a numerical rating for a performance characteristic according to the scale from 1 to 10, as shown in Figure 5-1 (also, see Appendix F, Tables F-1 and F-2). The response rating of the vehicle to throttle commands was based on the observed levels of performance, consistency and smoothness. Each data point represented an average of two drivers' ratings.

UNACCEPTABLE				BORDER-LINE	ACCEPTABLE				
1	2	3	4	5	6	7	8	9	10
POOR	POOR	POOR	DRIVER WILL COMPLAIN	BORDER-LINE	BARELY ACCEPT-ABLE	FAIR	GOOD	VERY GOOD	EXCELLENT

Figure 5-1. Vehicle Evaluation Rating System

Among the characteristics evaluated were constant vacuum accelerations or "crowds." In these tests, various depths of constant manifold vacuum commands were explored between speed ranges of 20-30 mph, 30-40 mph, 40-50 mph, and over 50 mph. In related tests of part-throttle accelerations, the vehicle was accelerated by a constant-throttle command. In these "cross-sections," the vehicle was subjected to step throttle-input commands of different depths at varying initial speeds. Again, carefully chosen cross-section points were established as representative of the entire matrix of possible combinations, ranging from low-speed/light-throttle to higher-speed/heavy-throttle-commands.

Another set of transient performance response tests was carried out with the engine fully warmed. These tests differed from crowd and cross-section testing in that the throttle-input command varied (see Appendix F, Tables F-1 and F-2).

A series of constant-speed, road-load points was also observed and rated. These measurements were taken at speeds of between 20 and 55 mph. For a steady-speed cruise, the engine should ideally be free from surge or unevenness. Idle was rated after the highway cruise. A wide-open throttle acceleration of from 0 to 30 mph was also performed. After this series of tests, the car was parked in the sun and shut off. The vehicle was allowed to soak for approximately 10 minutes. After the soak, the engine was re-started and the idle quality was rated in neutral and drive. Tip-ins were performed after this hot soak to search for any soak-related transient response problems.

The rating results of the hot engine driveability tests are given in Table 5-1. Essentially, the Micro-carburetor performed as well as the Rochester, except in one area. A hesitation on WOT acceleration was present, again due to the accelerator pump calibration.

C. ANGULARITY TEST RESULTS

In angularity testing, the fuel system's sensitivity to fuel slosh and to changes in the float level were examined. Angles of carburetor tilt were measured on two appropriately rescaled AMMCO Model 7350 "U-tube" accelerometers, mounted inside the vehicle.

The first phase of angularity testing was static angularity. The behavior of the engine idle was monitored with the vehicle on various inclined surfaces. With the car in "park," the engine idle vacuum was recorded before and after a 5-minute idle on a shallow slope and then again on a steep slope. Table 5-2 shows the results of the static tests. All tests from the four angles (front-up, rear-up, right-side-up, and left-side-up) yielded comparably small deterioration in idle quality. The only exception was the steep rear-end-up test. In this test, the Micro-carburetor's idle quality and idle speed increased slightly. The unorthodox placement of the float bowl at the rear of the Micro-carburetor had the effect of adding extra fuel to the idle system when the carburetor was tilted forward. The increased depth of fuel in the bowl over the idle jet apparently richened the idle.

The second phase of the angularity testing was the dynamic test. Table 5-3 and Appendix F, Tables F-8 and F-9, give the results in lateral acceleration (ft/sec^2), read directly from the two on-board accelerometers. The vehicle was taken to its maximum limits of forward acceleration, forward deceleration, rearward acceleration, rearward deceleration, and lateral skidpad acceleration. Stalls were noted appropriately.

The Rochester and the Micro-carburetor fared about equally well on all dynamic angularity tests, except for the forward-braking tests. Here, the Rochester experienced a persistent stall at 30 ft/sec^2 (0.94 g) while the Micro-carburetor did not. This may have been a result of the rear-mounted float bowl, which gave the Micro-carburetor an improved idle quality in the rear-end-up static tests. The Micro-carburetor seemed to be less sensitive than the Rochester to increases in pressure head at the front end of the float bowl.

Table 5-1. Hot Driveability Test Results

		RATINGS		
	SPEED	MICRO-CARB	BASELINE	CONCLUSION
CROWDS: CONSTANT VACUUM ACCELERATIONS	20-55 MPH	6.8	7	=
CRUISES: CONSTANT SPEED	20-55 MPH	6.5	7	=
TIP INS: THROTTLE RESPONSE	20-55 MPH	6.5	6.5	=
W.O.T.:	0 -30 MPH	5	7.5	-
P.T.: CONSTANT THROTTLE ACCELERATIONS	0 -30 MPH	7	7	=
IDLE QUALITY:		6.5	6.5	=
IDLE QUALITY AFTER HOT RESTART:		5	5.5	=
HOT RESTART TIME:		0.8 sec	1.8 sec	+

Table 5-2. Static Angularity Test Results

BASELINE				MICRO-CARBURETOR			
TEST	INITIAL IDLE VAC in. Hg	FINAL IDLE VAC in. Hg	REMARKS	TEST	INITIAL IDLE VAC in. Hg	FINAL IDLE VAC in. Hg	REMARKS
LEVEL	17.6 ±.2	17.2 ±.2	SAME	LEVEL	18 ± .5	17.5 ± .5	SLIGHT ROUGH
FRONT UP 10°	19.25	18.4	SLIGHT LOADING RICH	FRONT UP 10°	17.5 ± .5	16.5 ± .5 +	SLIGHT ROUGH
BACK UP 10°	17.5	17.0	VERY ROUGH LEAN	BACK UP 13°	18.25 ±.25	16.5 ± 75	SLIGHT ROUGH
FRONT UP 16°	19.2	18.8	VERY SLIGHT ROUGH	FRONT UP 14.5°	17 ± .5	16.75 ± .5	SLIGHT ROUGH
BACK UP 16°	16 ± .5	16.5 ± .5	SLIGHT ROUGH LEAN	BACK UP 17.5°	17.5 ± .25	19.75	MAJOR INCREASE IN RPM RICH
LEFT UP 11.5°	17.4	17.2	SAME	LEFT UP 12°	17.25 ± .5	16.5 ± .5	SLIGHT ROUGH
RIGHT UP 13°	18.0	17.4	SLIGHT ROUGH	RIGHT UP 12°	18 ± .5	17 ± .25	SAME

Table 5-3. Dynamic Angularity Test Results

TEST	MICRO-CARB	BASELINE
RIGHT TURN	SATISFACTORY	SATISFACTORY
LEFT TURN	SATISFACTORY	SATISFACTORY
FORWARD BRAKING	SATISFACTORY	STALL AT 30 ft/sec^2
BACKWARD BRAKING	SATISFACTORY	SATISFACTORY
FORWARD ACCELERATION	SATISFACTORY	SATISFACTORY
BACKWARD ACCELERATION	SATISFACTORY	SATISFACTORY

SECTION VI

GENERAL DISCUSSION OF TEST RESULTS

The Micro-carburetor has demonstrated the ability to increase the thermal efficiency of the test engine and thereby reduce the amount of fuel consumed ranging from 9.7% (see Table 4-2) to 18.1% (see Table 4-4) on the FTP cycle. Examination of the engine dynamometer data provides insight into the mechanism of the thermal efficiency improvement. Points B, C, D, and E were the leanest observed in the test series (see Table 3-1). The Micro-carburetor showed nearly double the exhaust oxygen content of the Rochester (see Appendix B, Figures B-5 and B-10). While points C and E had improved mixture distribution (see Figure 3-12), points B and D were the only indications of distribution degradation with the Micro-carburetor. Under these conditions, the engine's misfire rate should increase with the Micro-carburetor; this is true especially at point B, where three cylinders ran below $\phi = 0.790$ (see Figure 3-11a). Comparison of the unburned HC content of the exhaust (see Appendix B, Figures B-2 and B-7) indicates that the high HC levels usually attendant with misfires were not present. The HC levels generally declined with the Micro-carburetor. This is an indication that the mixture preparation of the Micro-carburetor was superior to that of the Rochester at those test points.

The Micro-carburetor demonstrated considerable fuel savings over the Rochester carburetor. At warm idle, the Micro-carburetor consumed 13.2% less fuel than the baseline (see Figure 3-7). This translates into a savings of 0.01 gallons (0.0381 ℓ) for every 5 minutes of idling. Considerable fuel savings also occurred at the higher steady-state load points. This was the result of sizable improvements in thermal efficiency and cylinder-to-cylinder equivalence ratio distribution (see Figures 3-9 and 3-12) at the higher loads.

The FTP urban cycle data showed areas of strength and weakness in the Micro-carburetor. Comparison of the cold-start FTP tests between the two carburetors (see Tables 4-1 and 4-2) showed that the Micro-carburetor's CO emissions were higher than the Rochester's CO emissions. Although other emissions increased, all fell within the EPA standards. Fuel economy improved 9.7% with the Micro-carburetor (see Table 4-2) allowing for equal spark advance. The hot-start test results (see Table 4-3) indicated that the Micro-carburetor performed well once the engine was warm. The Micro-carburetor showed a fuel economy improvement of 18.1% over the Rochester with direct manifold vacuum spark advance (see Table 4-4). The CO production of the Micro-carburetor was nearly half that of the Rochester in the hot-start tests (see Table 4-4), while in the cold-start tests (see Table 4-2), the CO production of the Micro-carburetor was nearly double that of the Rochester. The higher CO emissions and smaller fuel economy improvements of the Micro-carburetor in the cold-start tests were both indications of the overly rich operation of the cold engine. Because the choke determines the final equivalence ratio of a cold engine, the higher CO and smaller fuel economy gains for the Micro-carburetor in the cold-start tests as opposed to the hot-start tests were indications that the Micro-carburetor performed poorly in the cold-start portion of the FTP. This is further evidenced in the bag-by-bag data shown in Appendix A, Table A-1, where the Micro-carburetor demonstrated significantly higher CO in bag 1 (the cold-start portion of the FTP) but equal or lower CO than the Rochester in bags 2 and 3 (the hot-start portion of the FTP). If the choke in the Micro-carburetor operated as well as the choke in the Rochester, similar fuel economy improvements and CO reductions should result in both the cold-start and the hot-start FTP tests. This evaluation of the Micro-carburetor choke system was done on the basis of equal spark advance between the two carburetors. The spark advance strategy differences did not account for the significant fuel economy changes with the Rochester carburetor. This infers that the Micro-carburetor may not receive a fuel economy benefit from utilizing a ported spark advance strategy.

The hot-start emissions data look promising for the Micro-carburetor (see Tables 4-3 and 4-4). Compared to the baseline Rochester, CO improved 37.3% and NO_x remained similar. The HC remained low, although it was nearly double the baseline Rochester's value. When direct manifold vacuum spark advance was applied to the Rochester-equipped engine, all the exhaust emissions increased. With equal spark advance, the Micro-carburetor showed a 46.8% reduction in CO with nearly equal HC and NO_x; this shows the potential of the Micro-carburetor to decrease CO emissions by lean operation. From the high amount of deceleration-generated HC observed, it is inferred that improved levels of HC emissions are also possible with improved control of deceleration mixtures. NO_x emissions did not show a significant change from stock operation, even though the Micro-carburetor operates with more off-idle spark advance. This seems to suggest that less NO_x is possible for the Micro-carburetor with equal spark advance. This is possible due to the more even cylinder-to-cylinder mixture distribution, which caused more consistent cyclinder-to-cylinder combustion temperatures.

Driveability test results showed that a reasonably good level of performance was maintained with the Micro-carburetor. Two problem areas were uncovered which affected FTP emission levels. The choke system of the prototype Micro-carburetor needed better integration with the fast-idle device. Also, the accelerator pump operation was slightly deficient in fuel delivery.

SECTION VII

CONCLUSIONS

The Micro-carburetor prototype demonstrated a fuel economy advantage over the baseline Rochester carburetor. Even though the stock Rochester typifies a well-developed carburetor, fuel economy improvements of 9.7% to 18.1% were achieved with the Micro-carburetor for the cold-start and hot-start tests, respectively (see Tables 4-2 and 4-4). The differences in the fuel economy improvements between the hot-start and cold-start tests indicated that the Micro-carburetor could be developed even further to save additional fuel.

The emissions tests indicated the potential to dramatically reduce CO production, while the unburned HC tended to increase slightly but remained low. The generation of NO_x was unaffected by the Micro-carburetor, even with the increase in off-idle spark advance.

The improvements in engine performance generally reinforce the Micro Carburetor Corporation's claims of improved atomization and cylinder-to-cylinder distribution. An improvement in thermal efficiency was documented at every point in the engine dynamometer tests.

The basic design of the Micro-carburetor is sound. However, it is not yet ready for production. Certain development-related problems do exist. These problem areas will require special effort but by no means do they necessitate any major change in strategy. Some of the areas needing more work are power valve timing, accelerator pump timing and volume, choke control, fast-idle control, and deceleration mixture control. These calibration element changes are to be expected on a prototype carburetor that has not yet had the benefit of a carburetor flowstand analysis.

In the final analysis, the Micro-carburetor can lower fuel consumption by a significant amount. In addition, it has the potential to reduce emissions through a detailed analysis and recalibration effort.

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3. R.S. Spindt, "Air-Fuel Ratios from Exhaust Gas Analysis," SAE Paper 650507, 1965.

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APPENDICES

A

through

F

APPENDIX A, TABLE A-1 - FTP EMISSIONS

Top Line - Total Grams, Bottom Line - Grams per Mile

TEST #	DATE	BARO psia	REL HUM,%	BAG 1 NOx	BAG 1 CO	BAG 1 HC	BAG 2 NOx	BAG 2 CO	BAG 2 HC	BAG 3 NOx	BAG 3 CO	BAG 3 HC
12	11/04/80	14.12	25.69	11.50 3.19	83.11 23.09	5.90 1.64	7.21 1.85	4.20 1.08	.786 .200	9.39 2.61	18.69 5.19	1.44 .400
13	11/18/80	14.17	12.72	11.66 3.24	85.17 23.66	6.89 1.91	7.77 2.04	2.99 .788	.904 .238	9.54 2.65	9.26 2.57	1.21 .336
14	11/19/80	14.16	13.12	11.65 3.24	85.75 23.82	5.64 1.57	7.40 1.90	1.82 .468	.936 .240	9.72 2.86	6.23 1.83	.893 .263
15	11/20/80	14.14	12.62	11.41 3.17	78.91 21.92	5.22 1.45	7.57 1.94	2.33 .598	.530 .136	9.81 2.89	8.28 2.43	1.08 .318
AVE 12-15		14.15	16.04	11.55 3.21	83.23 23.12	5.91 1.64	7.49 1.93	2.83 .733	.789 .203	9.61 2.79	10.61 3.01	1.16 .329
18	12/17/80	14.10	24.61	12.58 3.49	94.91 26.36	9.00 2.50	10.19 2.61	2.25 .576	1.61 .412	10.88 3.02	11.12 3.09	1.89 .524
19	12/18/80	14.11	38.57	12.33 3.42	83.66 23.24	6.49 1.80	8.64 2.22	2.51 .643	1.36 .349	10.14 3.07	15.10 4.58	1.92 .583
AVE 18-19		14.105	31.59	12.45 3.45	89.29 24.80	7.75 2.15	9.42 2.42	2.38 .610	1.49 .381	10.51 3.05	13.11 3.84	1.91 .554
20	01/07/81	14.09	19.84	8.19 2.28	170.22 47.28	14.51 4.03	7.10 1.82	2.97 .760	2.39 .631	10.80 3.00	4.31 1.20	2.18 .610
21	01/08/81	14.10	29.77	11.71 3.25	164.96 45.82	9.94 2.76	8.82 2.26	1.93 .494	1.71 .438	11.29 3.14	6.95 1.93	1.77 .491
22	01/09/81	14.09	20.32	11.71 3.25	155.03 43.07	8.65 2.40	8.66 2.22	1.60 .410	1.31 .335	10.48 2.91	8.20 2.28	1.50 .417
AVE 20-22		14.09	23.31	10.54 2.93	163.40 45.39	11.03 3.06	8.19 2.10	2.17 .555	1.80 .462	10.86 3.02	6.49 1.80	1.82 .506
24	01/14/81	14.08	36.06	12.25 3.40	165.50 45.98	43.10 11.97	9.68 2.48	1.85 .474	1.49 .382	11.31 3.14	3.49 .970	1.95 .541

TABLE A-1 (Cont.d)
Top Line - Total Grams, Bottom Line - Grams per Mile

TEST #	TEST NOx	TEST CO	TEST HC	TEST CO_2	FUEL ECONOMY W.T.	FUEL ECONOMY C.B.	CONFIGURATION
12	28.09 2.33	106.00 6.74	8.13 .533	7020.5 643.4	12.97	13.52	Rochester-Ported Spark
13	28.97 2.43	97.43 5.99	9.01 .610	7060.5 647.1	13.20	13.47	" "
14	28.78 2.43	93.79 5.65	7.49 .520	7024.4 653.1	12.99	13.36	" "
15	28.80 2.45	89.52 5.49	6.83 .455	7023.1 653.3	13.04	13.37	" "
AVE 12-15	28.66 2.41	96.69 5.97	7.87 .535	7032.1 649.2	13.05	13.43	" "
18	33.65 2.91	108.27 6.59	12.49 1.12	6883.3 628.5	13.04	13.82	Rochester-Manifold Spark
19	31.11 2.69	101.27 6.34	9.78 .711	6740.6 627.7	13.69	13.86	" "
AVE 18-19	32.38 2.80	104.77 6.47	11.14 .916	6812.0 628.1	13.36	13.84	" "
20	26.09 2.24	177.50 10.48	19.08 1.32	6568.2 596.5	13.98	14.37	Micro-Carburetor
21	31.82 2.71	173.83 10.24	13.41 .932	6487.5 589.1	14.96	14.58	"
22	30.85 2.62	164.83 9.73	11.45 .784	6404.7 580.6	15.00	14.82	"
AVE 20-22	29.59 2.52	172.05 10.15	14.65 1.01	6486.8 588.7	14.65	14.59	"
24	33.25 2.85	170.9 10.0	46.54 2.82	6432.4 583.2	14.57	14.59	"
1975 STANDARD	3.1	15.0	1.5	ALL TESTS AT 12 hp/4000 lb Inertia Weight, 12-18 Hr Soak Times, Ambient Temp. 75° ± 5°. FTP.			

APPENDIX B TABLE B-1

TEST CONFIG Baseline Distribution Tests

TEST # 26 BARO, In Hg 28.83 @ 70 °F. DATE 2/5/81

TEST POINT	rpm-TORQUE	POINT CODE	ϕ	SPARK AD-VANCE °BTDC	η_T	MANIF. PRES. psia	MANIF. VAC In. Hg	EXH PRES In. H_2O	CARB FUEL psig	EGR PRES psia	BARO. PRES. psia	AFR	AIR lbm/hr	FUEL lbm/hr	bhp	bsfc lbm/bhp-hr
001	1940-175.5	J	1.233	28.0	28.5	10.76	6.76	1.83	5.87	11.07	14.08	11.80	446.63	37.85	64.1	.591
901	1920-175.9	J	1.165	28.6	29.8	10.68	6.92	1.80	4.78	11.09	14.08	12.49	455.01	36.43	64.1	.568
002	1930-117.6	I	.984	36.75	34.5	8.83	10.67	1.43	5.74	11.03	14.07	14.79	343.87	23.25	43.1	.539
902	1930-119.5	I	.982	36.9	34.8	8.86	10.62	1.44	5.43	11.02	14.075	14.89	346.94	23.30	43.8	.532
003	2020- 57.7	H	.926	38.9	31.9	6.67	15.09	1.06	5.88	11.15	14.08	15.41	261.66	16.98	22.2	.765
903	2015- 58.8	H	.942	38.9	31.8	6.61	15.19	1.05	6.02	11.15	14.07	15.44	265.88	17.22	22.6	.762
004	1540-140.9	G	.999	27.7	32.0	10.21	7.87	1.33	5.58	11.64	14.075	14.57	323.60	22.21	41.3	.538
904	1590-137.7	G	.994	29.4	32.5	9.97	8.36	1.34	5.45	11.54	14.075	14.64	325.89	22.26	41.6	.535
005	1630-115.3	F	1.020	33.5	32.6	9.21	9.91	1.26	5.56	11.55	14.075	14.26	284.06	19.92	35.7	.558
905	1550-117.2	F	.945	31.1	31.8	9.53	9.25	1.23	5.46	11.78	14.075	15.39	299.64	19.47	34.5	.564
006	1610- 55.5	E	.906	36.6	29.8	7.03	14.35	.860	4.25	11.44	14.08	16.05	215.87	13.45	17.1	.787
906	1635- 57.2	E	.904	36.8	29.4	7.02	14.37	.898	6.38	11.44	14.08	16.09	224.62	13.96	17.8	.784
007	1195- 80.2	D	.896	26.8	27.5	8.95	10.44	.818	6.62	12.01	14.08	16.24	207.38	12.77	18.1	.706
907	1215- 81.2	D	.960	26.8	27.6	8.98	10.38	.855	6.04	12.02	14.08	15.16	200.11	13.20	18.8	.702
008	1205- 57.2	C	.947	29.3	26.2	7.47	13.46	.646	6.47	11.92	14.08	15.37	169.22	11.01	13.1	.840
908	1200- 58.4	C	.940	29.3	25.9	7.59	13.21	.660	6.01	11.92	14.08	15.48	172.29	11.13	13.3	.837
009	1035- 46.1	B	.969	18.8	25.1	6.04	16.38	.460	6.86	13.10	14.085	15.02	127.07	8.46	9.1	.930
909	1010- 45.4	B	.974	16.3	24.3	6.02	16.41	.459	7.71	13.16	14.08	14.94	126.54	8.47	8.7	.974
010	585- 37.7	A	.905	5.8	20.9	7.59	13.21	.296	8.22	14.04	14.08	16.07	84.05	5.23	4.2	1.250
011	2925-228.9	WOT	1.146	25.4	29.6	12.93	2.36	3.76	5.11	13.15	14.09	12.70	933.20	73.48	127.3	.577

APPENDIX B TABLE B-2

TEST CONFIG Micro-Carb Distribution Tests

TEST # 27 BARO, In Hg 28.97 @ 70 °F. DATE 2/11/81

TEST POINT	rpm - TORQUE	POINT CODE	ϕ	SPARK ADVANCE °BTDC	η_T	MANIF. PRES. psia	MANIF. VAC In. Hg	EXH PRES In. H_2O	CARB FUEL psig	EGR PRES psia	BARO. PRES. psia	AFR	AIR lbm/hr	FUEL lbm/hr	bhp	bsfc lbm/bhp-hr
001	2000-174.4	J	1.023	27.2	35.01	11.02	6.38	1.73	4.08	10.93	14.155	14.22	458.03	32.21	66.3	.486
901	2000-174.1	J	1.057	27.2	34.26	11.04	6.33	1.72	5.37	10.93	14.15	13.76	451.47	32.81	66.2	.496
002	1995-116.5	I	1.030	37.9	35.15	8.57	11.36	1.21	6.12	11.34	14.15	14.12	333.94	23.65	44.2	.535
902	1990-115.4	I	1.020	37.8	35.04	8.61	11.28	1.20	6.38	11.34	14.15	14.27	334.49	23.44	43.7	.536
003	1995- 57.5	H	.924	38.7	34.14	6.71	15.15	.875	4.52	11.92	14.15	15.74	243.66	15.48	21.7	.713
903	1975- 59.5	H	.919	38.7	32.90	6.82	14.92	.891	4.16	11.88	14.15	15.84	258.19	16.30	22.4	.726
004	1600-140.2	G	1.005	30.2	34.03	9.74	8.98	1.12	5.66	11.50	14.15	14.48	314.22	21.70	42.7	.508
904	1570-140.8	G	1.011	30.0	34.10	9.79	8.87	1.10	6.43	11.52	14.145	14.39	306.51	21.30	42.2	.505
005	1570-120.2	F	.992	33.7	34.33	8.86	10.77	.976	6.28	11.74	14.15	14.66	273.99	18.69	35.9	.521
905	1580-118.4	F	.980	33.9	33.90	8.85	10.79	.982	6.62	11.71	14.15	14.85	282.15	19.00	35.7	.532
006	1590- 58.4	E	.861	35.8	29.81	7.22	14.11	.760	5.78	12.17	14.15	16.90	226.80	13.42	17.6	.762
906	1585- 57.9	E	.853	35.8	29.64	7.16	14.21	.760	6.04	12.17	14.14	17.05	228.47	13.40	17.4	.770
007	1190- 80.1	D	.846	27.0	28.75	8.80	10.88	.697	6.26	12.30	14.145	17.19	211.95	12.33	18.3	.674
907	1200- 79.1	D	.840	27.7	28.68	8.68	11.27	.692	6.04	12.30	14.145	17.31	212.91	12.30	18.0	.683
008	1205- 57.8	C		28.8	26.86	7.66	13.19	.602	6.42	12.51	14.14			10.61	13.3	.798
908	1190- 58.4	C		28.8	26.26	7.63	13.27	.602	6.45	12.52	14.15			10.59	13.1	.808
009	1000- 46.1	B		25.5	25.02	7.20	14.15	.487	6.79	12.82	14.15			8.22	8.9	.923
909	1015- 46.6	B		25.6	25.31	7.14	14.27	.492	6.32	12.83	14.15			8.37	9.0	.930
010	575- 40.4	A		23.5	24.85	7.86	12.82	.268	6.79	13.55	14.155			4.57	4.4	1.039
011	2950-225.5	WOT	1.180	25.5	30.90	12.54	3.35	3.35	5.96	12.64	14.15	12.34	868.24	70.36	126.7	.555

APPENDIX B TABLE B-3

TEST CONFIG Micro-Carburetor Stock Exhausts

TEST # 28A BARO, In Hg 28.75 @ 70 °F. DATE 2/18/81

TEST POINT	rpm-TORQUE	POINT CODE	ϕ	SPARK AD-VANCE °BTDC	η_T	MANIF. PRES. psia	MANIF. VAC In. Hg	EXH PRES In. H_2O	CARB FUEL psig	EGR PRES psia	BARO. PRES. psia	AFR	AIR lbm/hr	FUEL lbm/hr	bhp	bsfc lbm/bhp-hr
1	2000-174.4	J	1.11	26.4	32.5	11.15	6.07	1.73	8.08	10.96	14.13	13.08	456.18	34.80	66.5	.523
2	2005-113.8	I	1.03	37.3	34.6	8.66	11.14	1.21	8.90	11.37	14.13	14.06	333.22	23.70	43.5	.545
3	1980- 56.5	H	.925	38.6	32.2	6.88	14.75	.891	8.53	11.95	14.125	15.73	254.35	16.17	21.3	.759
4	1620-138.3	G	1.03	31.0	33.3	9.67	9.07	1.12	7.92	11.51	14.125	14.09	312.66	22.19	42.6	.521
5	1610-117.5	F	1.04	34.7	33.1	8.75	10.93	.975	7.91	11.74	14.12	13.94	274.20	19.67	36.1	.545
6	1600- 59.0	E	.897	35.9	30.0	7.18	14.14	.767	6.57	12.17	14.125	16.22	220.59	13.60	18.0	.722
7	1225- 80.5	D	.894	28.7	29.2	8.65	11.14	.693	6.76	12.32	14.12	16.27	199.47	12.26	18.3	.670
8	1190- 56.9	C	.851	28.7	27.5	7.54	13.40	.600	7.14	12.53	14.12	17.09	173.80	10.17	13.0	.782
9	980- 47.1	B	.797	24.7	25.3	7.21	14.07	.480	7.50	12.84	14.12	18.25	145.09	7.95	8.8	.903
10	585- 42.7	A	.805	23.4	26.0	7.57	13.34	.247	7.95	13.61	14.12	18.08	80.28	4.44	4.7	.945

APPENDIX B TABLE B-4

TEST CONFIG Points 12-21 Baseline Ported Spark, Points 1-4 Baseline Manifold Spark, All with Stock Exhaust

TEST # 28B, 29 BARO, in Hg ______ @ 70 °F. DATE 2/18/81, 2/19/81

TEST POINT	rpm-TORQUE	POINT CODE	Φ	SPARK ADVANCE °BTDC	η_T	MANIF. PRES. psia	MANIF. VAC in. Hg	EXH PRES in. H_2O	CARB FUEL psig	EGR PRES psia	BARO. PRES. psia	AFR	AIR lbm/hr	FUEL lbm/hr	bhp	bsfc lbm/bhp-hr
12	1980-174.2	J	1.220	28.7	29.2	10.72	6.90	1.88	8.11	11.10	14.11	11.89	453.60	38.15	65.6	.582
13	2015-115.2	I	.988	37.7	34.3	8.64	11.13	1.49	9.19	10.92	14.105	14.72	358.43	24.35	44.2	.551
14	1990- 58.4	H	.936	38.9	32.1	6.64	15.20	1.06	9.56	11.21	14.105	15.55	258.28	16.61	22.1	.752
15	1600-139.1	G	.987	29.8	33.2	9.86	8.64	1.35	9.05	11.56	14.105	14.74	326.93	22.18	42.5	.522
16	1610-116.5	F	.977	33.2	33.1	9.09	10.22	1.24	9.03	11.61	14.11	14.90	291.81	19.59	35.9	.546
17	1600- 59.9	E	.918	36.2	30.0	7.00	14.47	.878	7.73	11.46	14.105	15.84	216.53	13.67	18.2	.751
18	1235- 81.2	D	.910	28.4	29.3	8.50	11.41	.820	7.90	11.88	14.105	15.98	202.47	12.67	19.2	.660
19	1210- 61.0	C	.945	29.0	27.0	7.54	13.37	.676	8.22	11.91	14.105	15.39	170.06	11.05	13.9	.795
20	1025- 46.8	B	.976	17.5	25.7	6.08	16.34	.478	8.70	13.09	14.105	14.90	123.07	8.26	9.1	.908
21	570- 38.4	A	.900	5.6	21.4	7.67	13.15	.300	9.14	14.00	14.10	16.17	81.17	5.02	4.2	1.195
1	1210- 59.5	C	.959	28.7	27.0	7.35	13.83	.647	10.12	12.00	14.145	15.16	164.64	10.86	13.7	.793
2	995- 47.0	B	.973	24.6	27.0	5.82	16.94	.428	7.71	13.61	14.14	14.96	113.40	7.58	8.8	.861
3	660- 23.9	A	.858	23.2	23.5	6.12	16.53	.258	8.21	14.11	14.14	16.96	71.40	4.21	3.0	1.403
4	660- 36.2	A	.857	23.4	25.9	6.55	15.45	.259	8.20	14.14	14.14	16.98	71.15	4.19	4.0	1.048

APPENDIX B TABLE B-5

TEST CONFIG Micro-Carburetor Distribution Retests

TEST # 30 BARO, In Hg 28.65 @ 70 °F. DATE 4/17/81

TEST POINT	rpm-TORQUE	POINT CODE	ϕ	SPARK ADVANCE °BTDC	η_T	MANIF. PRES. psia	MANIF. VAC In. Hg	EXH PRES In. H_2O	CARB FUEL psig	EGR PRES psia	BARO. PRES. psia	AFR	AIR lbm/hr	FUEL lbm/hr	bhp	bsfc lbm/bhp-hr
002	1990-115.6	I	1.030	36.8	34.9	8.66	11.00		6.00	11.33	14.065	14.13	332.3	23.52	43.7	.538
902	1985-118.2	I	1.000	36.5	35.4	8.78	10.75		5.60	11.25	14.06	14.50	341.6	23.56	44.7	.527
907	1195- 82.4	D	.937	28.4	29.9	8.16	12.06		5.36	12.38	14.065	15.53	186.4	12.00	18.8	.638
008	1215- 58.9	C	.872	28.7	27.3	7.66	13.04		5.89	12.43	14.065	16.69	179.8	10.77	13.5	.798
908	1220- 57.2	C	.868	28.9	27.0	7.55	13.26		5.86	12.43	14.065	16.77	180.1	10.74	13.3	.807
009	1010- 45.9	B	.814	25.4	25.0	7.17	14.04		6.31	12.75	14.065	17.88	145.4	8.13	8.8	.924
909	990- 45.9	B	.812	24.4	24.5	7.22	13.95		6.10	12.75	14.07	17.93	146.9	8.19	8.6	.952
010	600- 40.7	A	.826	23.4	25.5	7.20	13.98		6.59	13.58	14.065	17.62	79.5	4.51	4.6	.980

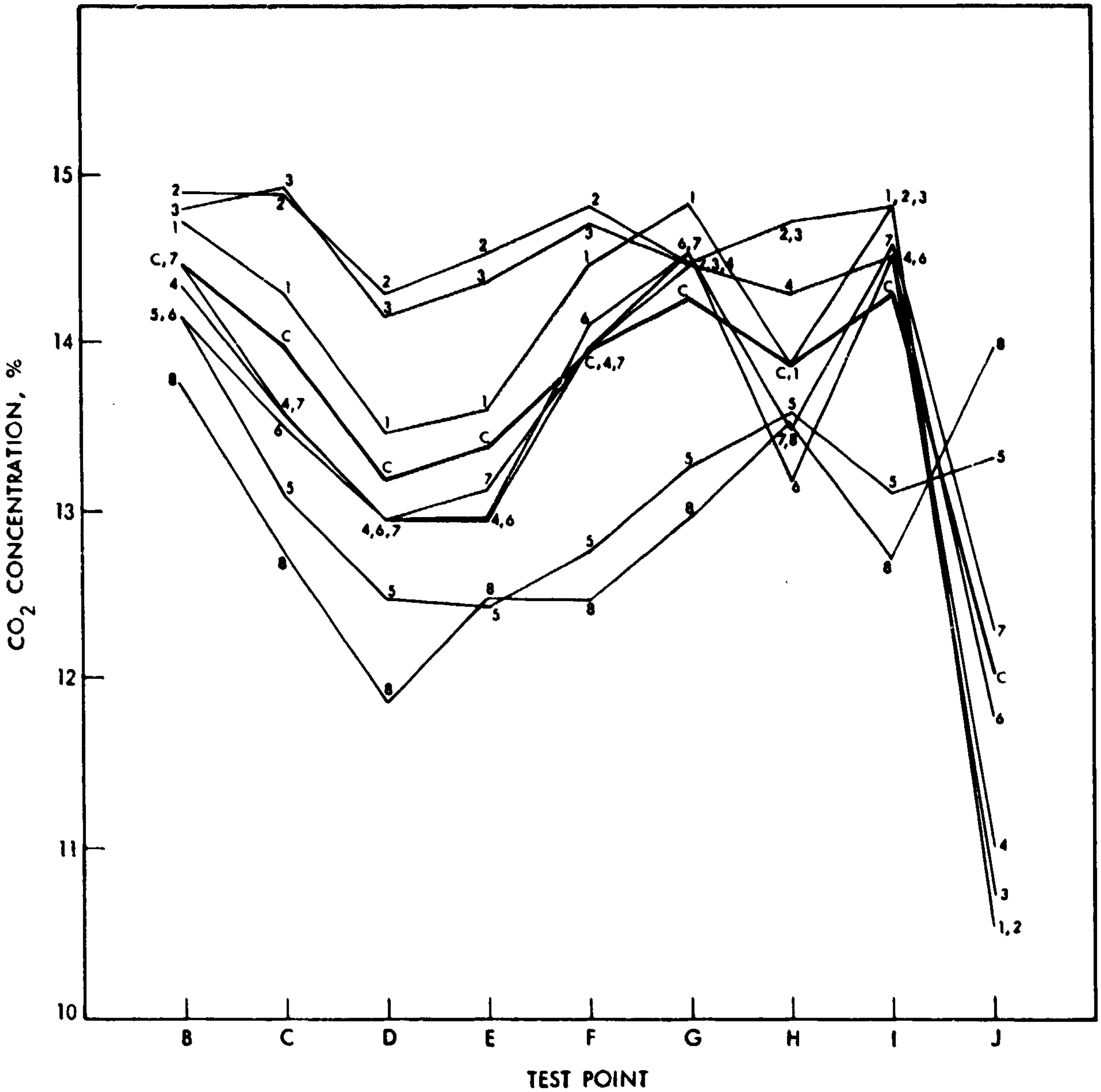

Figure B-1. Cylinder-to-Cylinder CO_2 Distribution, Baseline

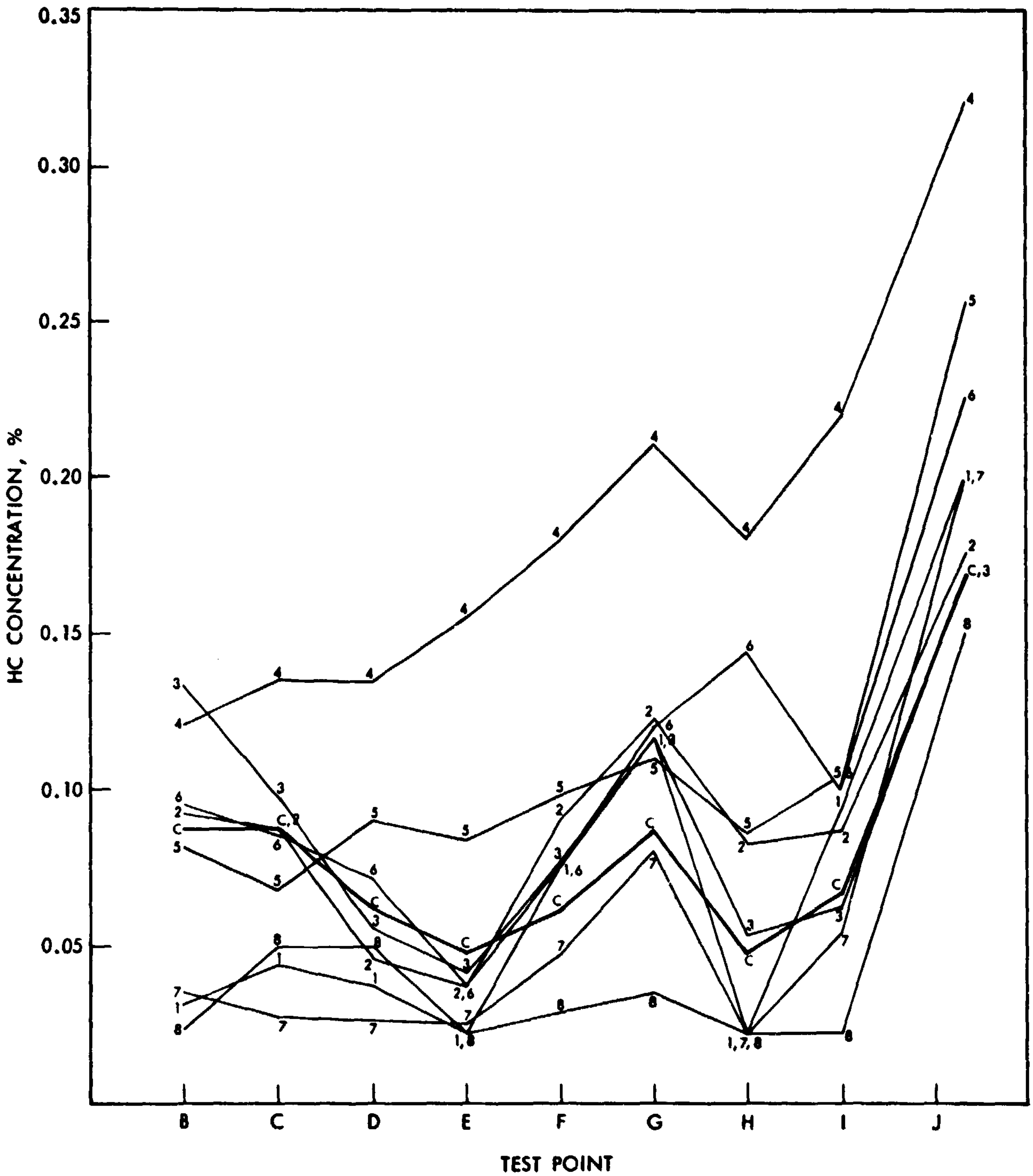

Figure B-2. Cylinder-to-Cylinder HC Distribution, Baseline

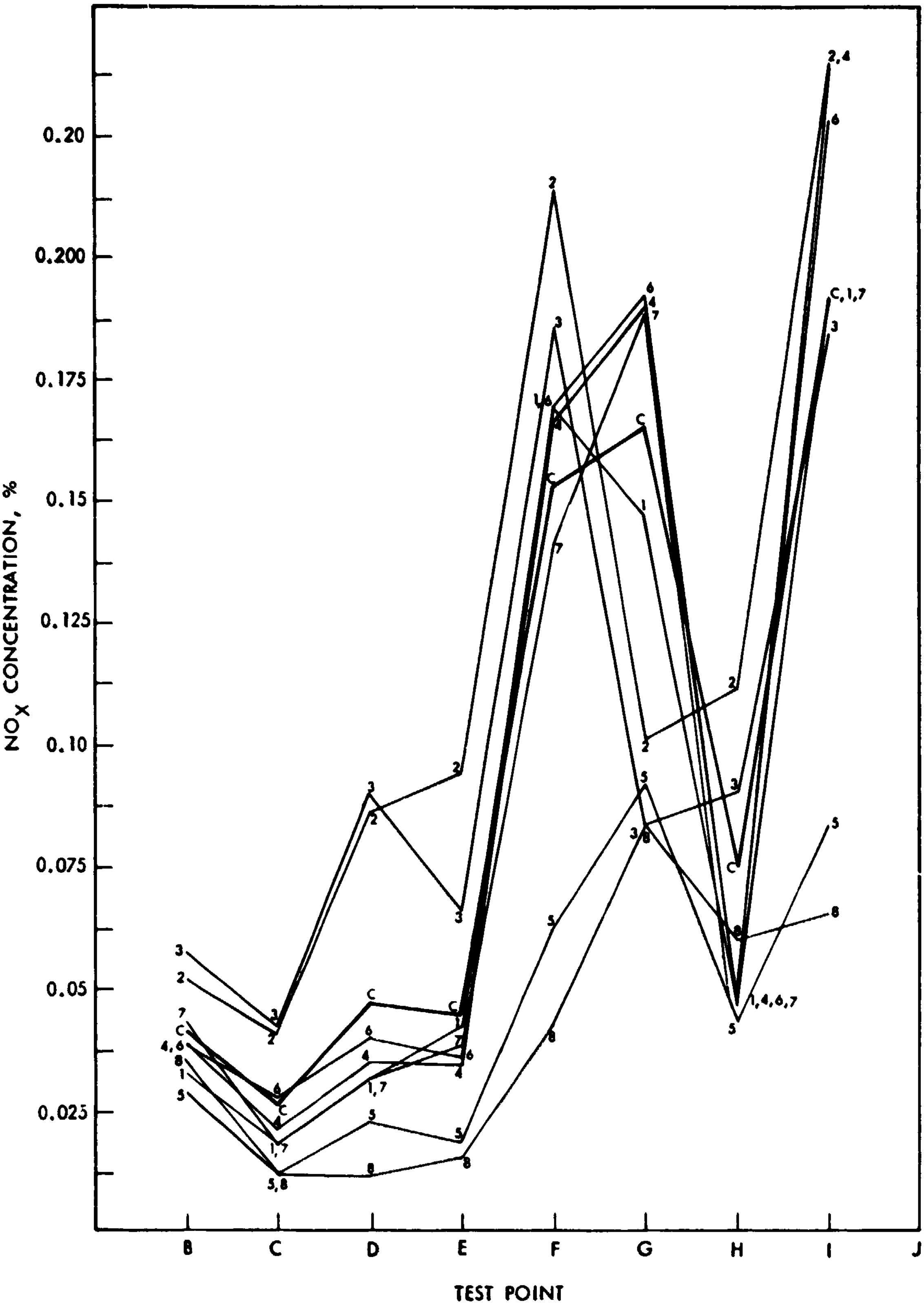

Figure B-3. Cylinder-to-Cylinder NO_x Distribution, Baseline

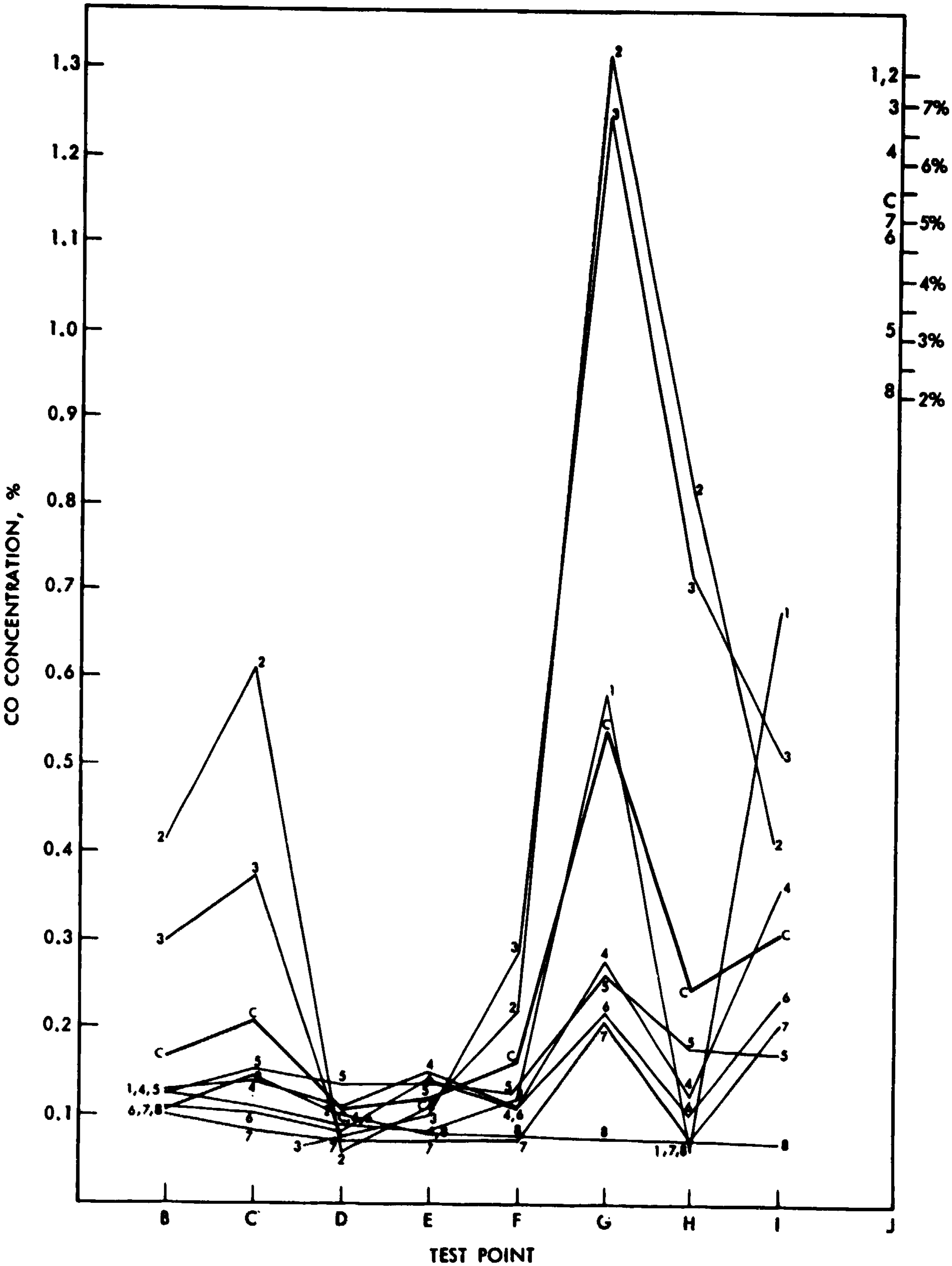

Figure B-4. Cylinder-to-Cylinder CO Distribution, Baseline

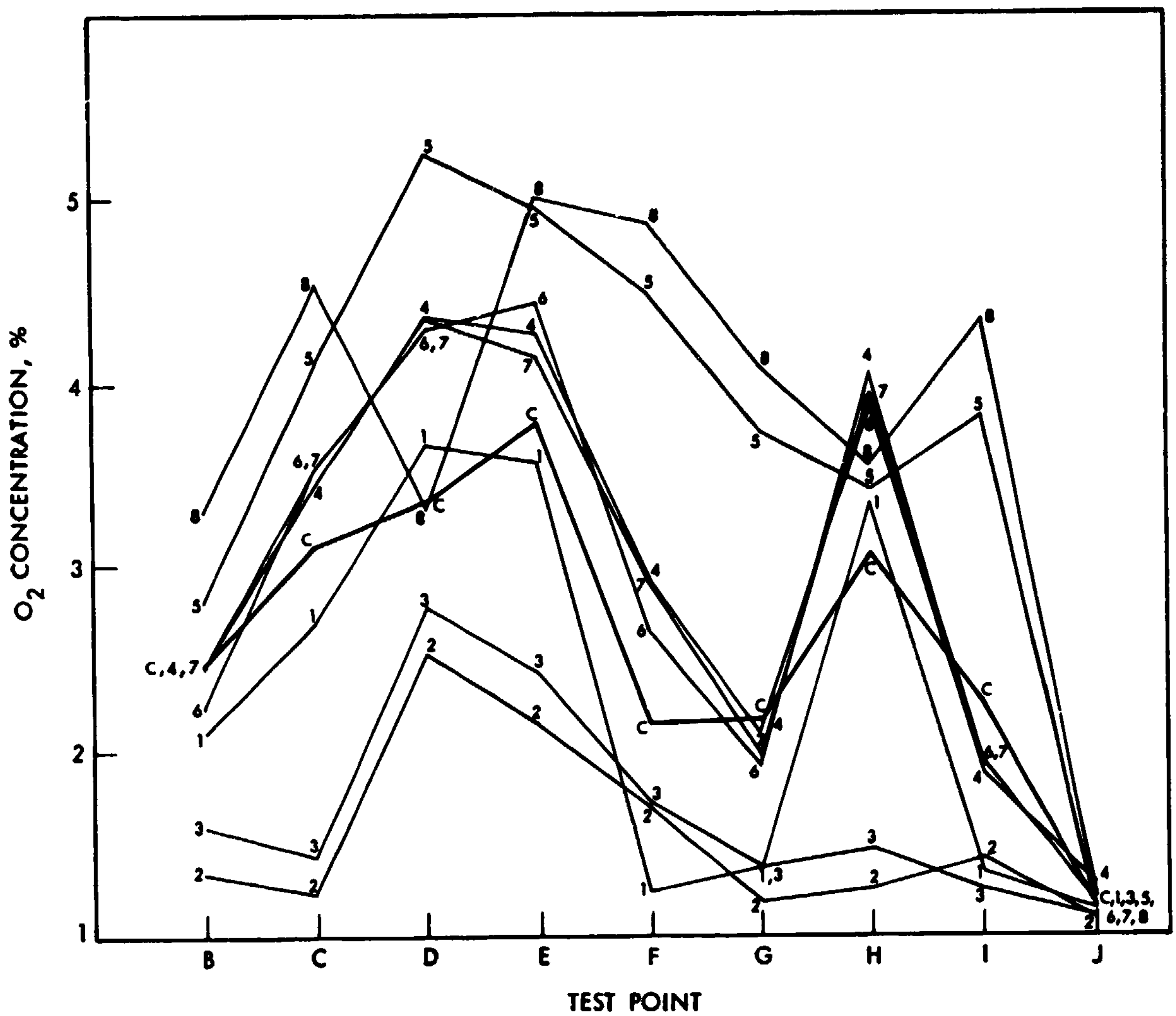

Figure B-5. Cylinder-to-Cylinder O_2 Distribution, Baseline

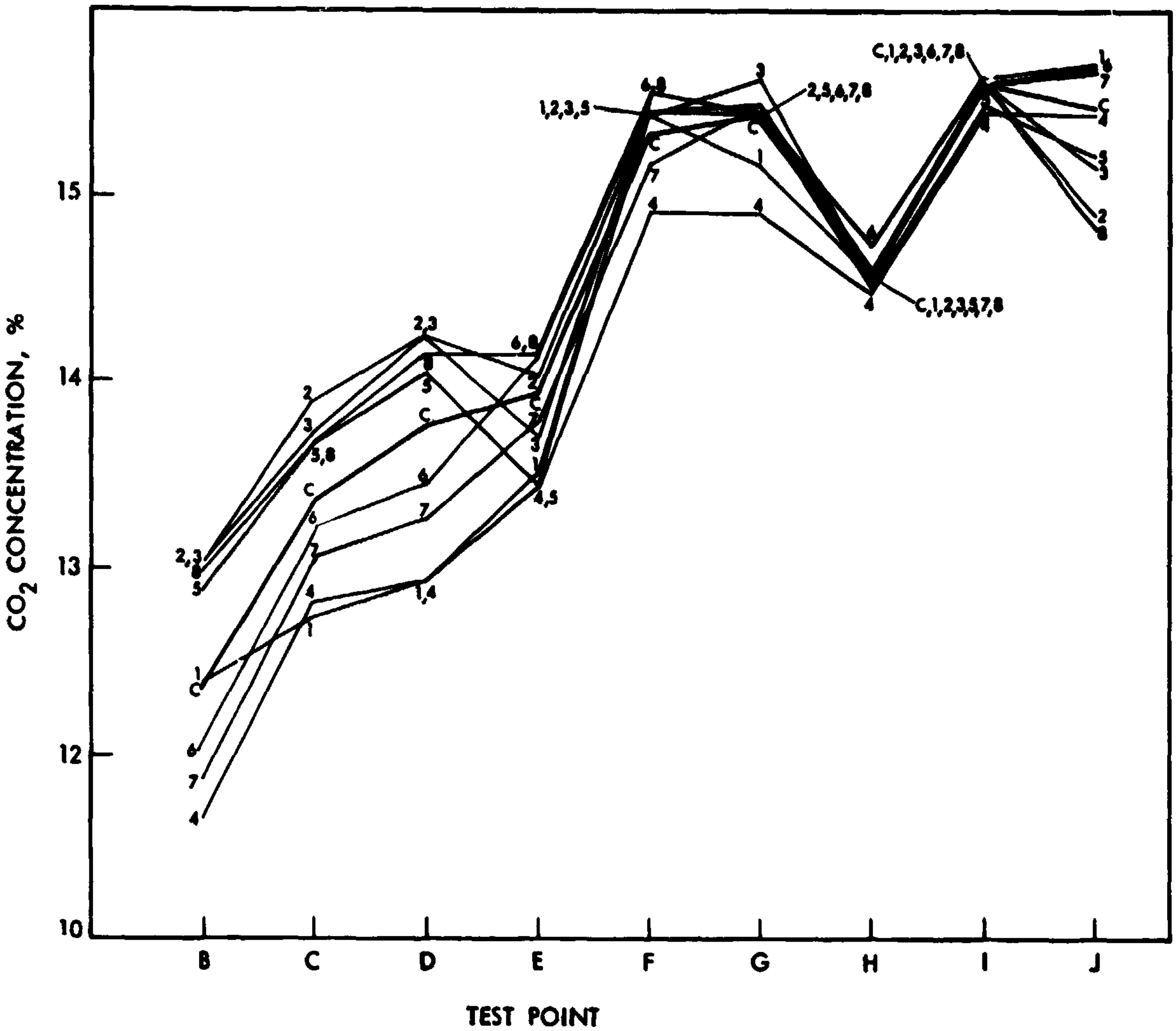

Figure B-6. Cylinder-to-Cylinder CO_2 Distribution, Micro-Carburetor

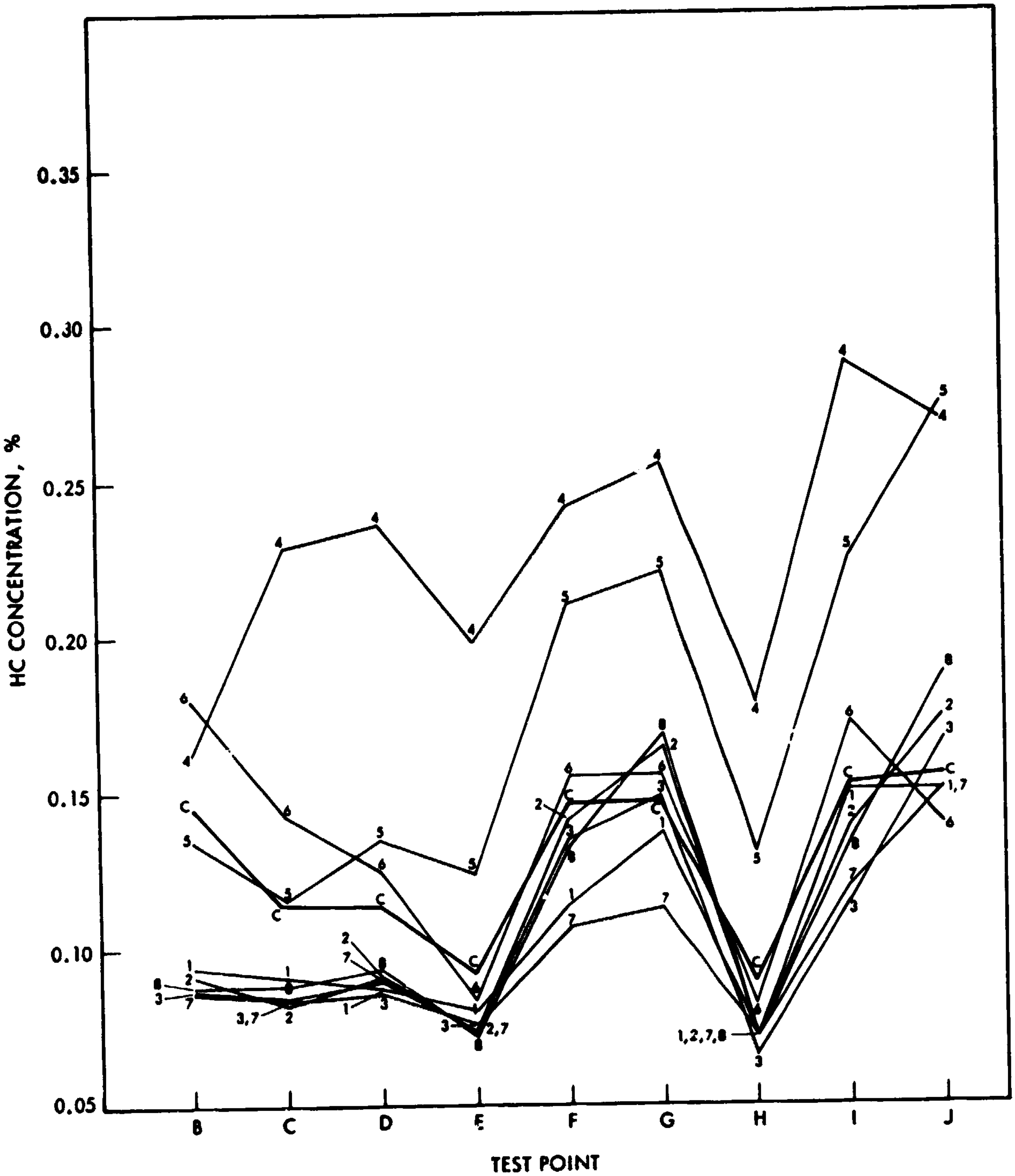

Figure B-7. Cylinder-to-Cylinder HC Distribution, Micro-Carburetor

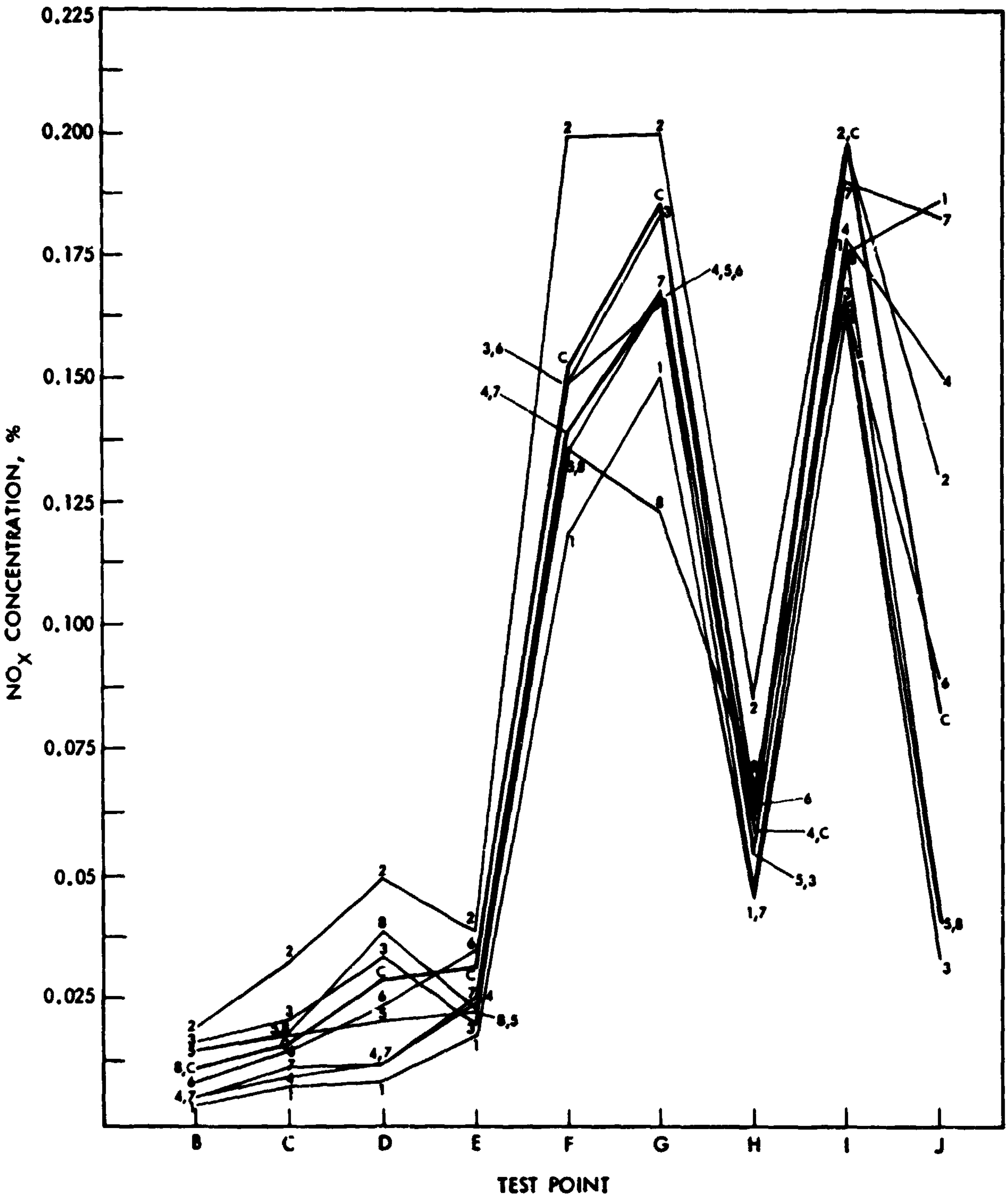

Figure B-8. Cylinder-to-Cylinder NO_x Distribution, Micro-Carburetor

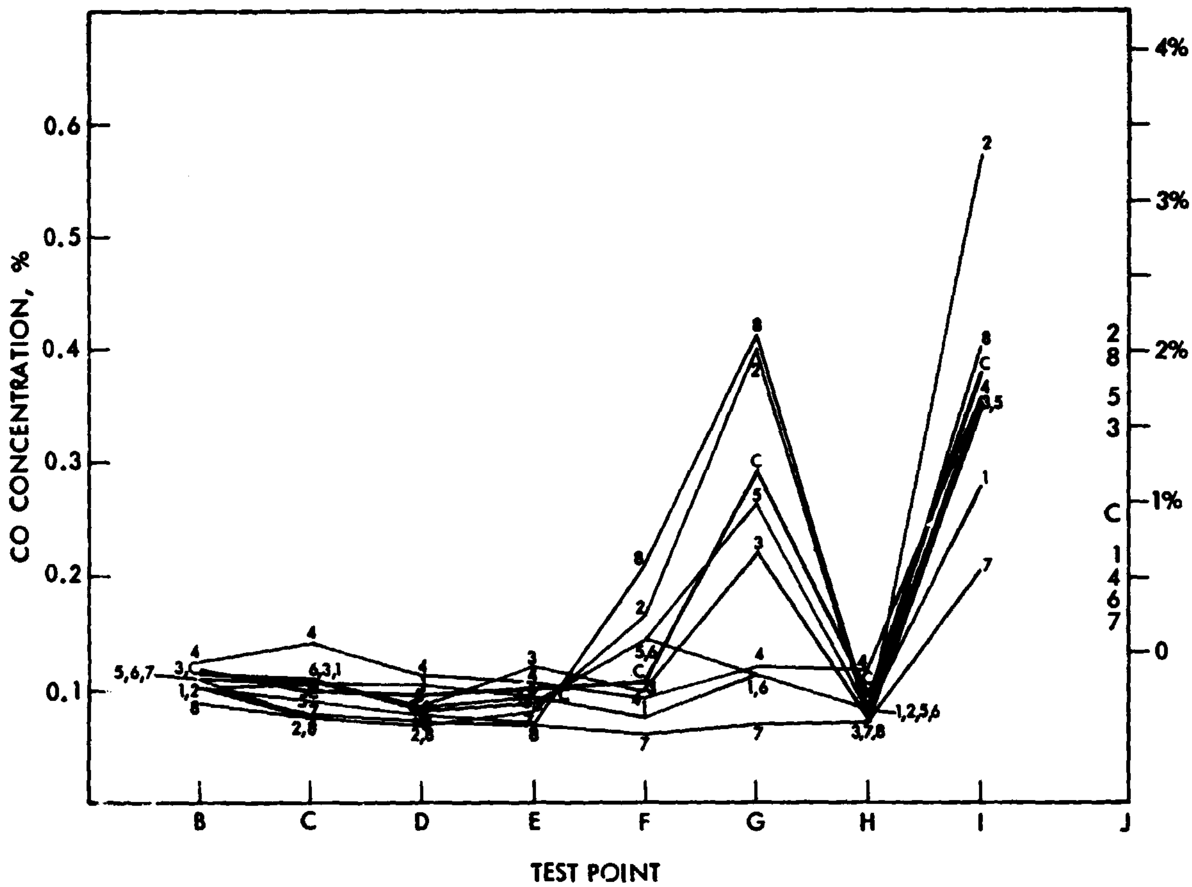

Figure B-9. Cylinder-to-Cylinder CO Distribution, Micro-Carburetor

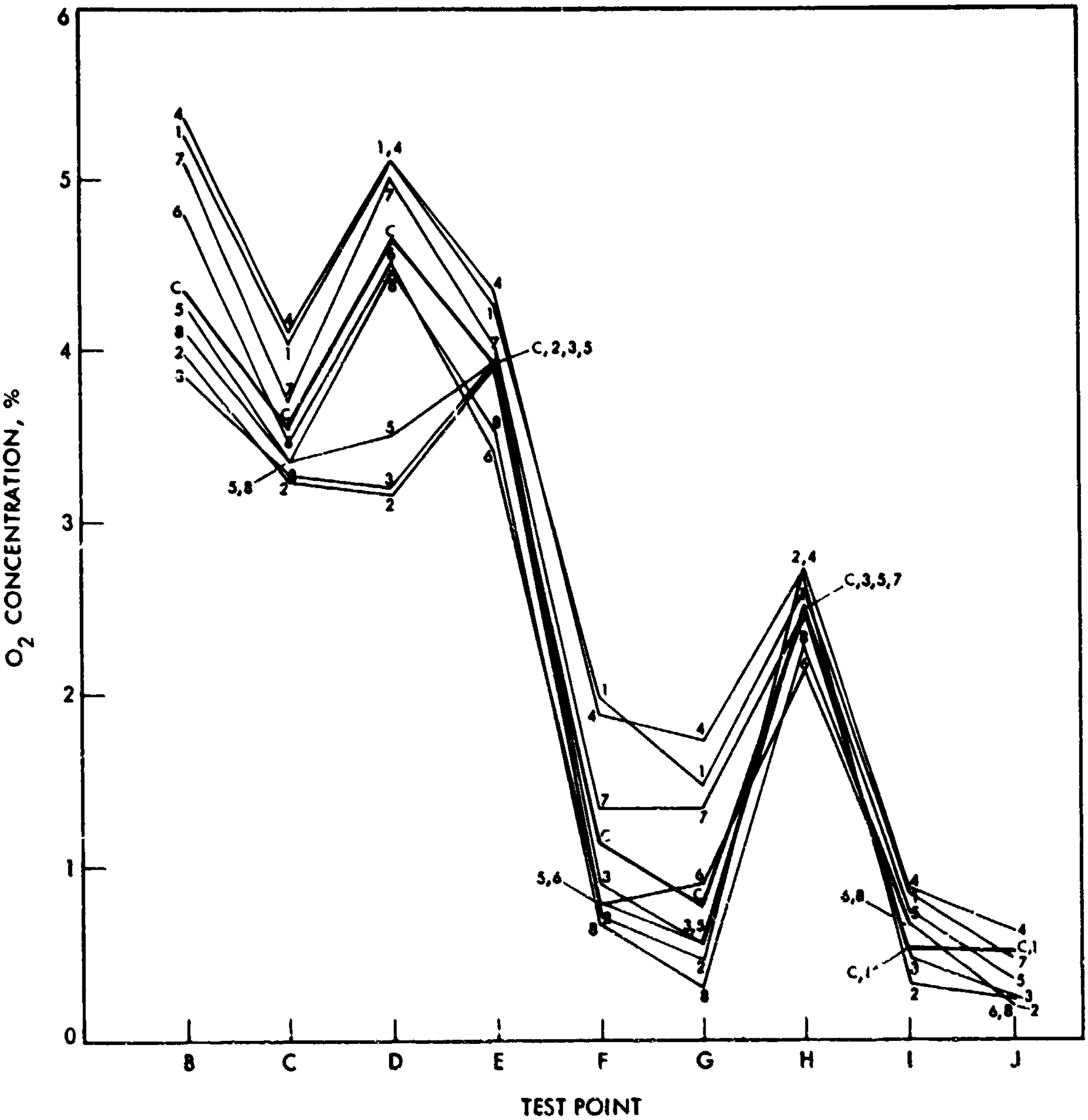

Figure B-10. Cylinder-to-Cylinder O_2 Distribution, Micro-Carburetor

APPENDIX C

Carbon Balance Technique for determining air-fuel ratios from exhaust emissions:

$$AFR = F_b \left[11.492\ F_c \left(\frac{1+R/2+Q}{1+R} \right) + \frac{120(1-F_c)}{3.85+R} \right] \qquad (C_1)$$

where:

$$F_b = \frac{\%CO + \%CO_2}{\%CO + \%CO_2 + \%HC} \qquad (C_2)$$

F_c = weight fraction of carbon in fuel =0.866 for Indolene Clear by JPL analysis

$$R = \frac{\%CO}{\%CO_2} \qquad (C_3)$$

$$Q = \frac{\%O_2}{\%CO_2} \qquad (C_4)$$

Example: CO = 1.31%, CO_2 = 14.44%, O_2 =0.20%, HC =0.12%, then substituting into C_2, C_3, C_4

$$F_b = \frac{1.31 + 14.44}{1.31 + 14.44 + .12} = 0.9924 \qquad (C_5)$$

$$R = \frac{1.31}{14.44} = 0.0907 \qquad (C_6)$$

$$Q = \frac{.20}{14.44} = 0.0138 \qquad (C_7)$$

Substituting C_5, C_6, C_7 into C_1

$$AFR = .9924 \left[11.492 \times 0.866 \left(\frac{1 + \frac{0.0907}{2} + 0.0138}{1 + 0.0907} \right) + \frac{120(1-.866)}{3.85 + .0907} \right] = 13.57 \Rightarrow \Phi = 1.07$$

Reference: "Air Fuel Ratios from Exhaust Gas Analysis," R.S. Spindt, Gulf Research and Development Company.

APPENDIX D

Thermal Efficiency Calculations

$$\eta_T = \frac{\text{work-out X 100\%}}{\text{chem. energy in.}} = \frac{\text{W X 100\%}}{\text{C.E.}} \qquad (D_1)$$

Terms defined as:

D = Dyno bhp

F = Fuel Flow $\frac{lbm}{hr}$

$$fhp = [(rpm)^2 \times 3.75 \times 10^{-6}] + [(rpm) \times 2.1368 \times 10^{-4}] + 2.5182 \qquad (D_2)$$

$$C.E. = F \times \text{heating value} = F \times 7.4809 \frac{hp\text{-}hr}{lbm} \qquad (D_3)$$

$$W = \text{work-out} = D + fhp \qquad (D_4)$$

Substituting D_2 into D_4

$$W = D + [(rpm)^2 \times 3.75 \times 10^{-6}] + [(rpm) \times 2.1368 \times 10^{-4}] + 2.5182 \qquad (D_5)$$

Substituting D_3, D_5 into D_1

$$\eta_T = \frac{D + [(rpm)^2 \times 3.75 \times 10^{-6}] + [(rpm) \times 2.1368 \times 10^{-4}] + 2.5182}{F \times 7.4809} \times 100\% \qquad (D_6)$$

Example: Dyno bhp = 43.7 bhp, Fuel Flow = 23.52 $\frac{lbm}{hr}$, rpm = 1990

Then:

$$W = 43.7 + [(1990)^2 \times 3.75 \times 10^{-6}] + [(1990) \times 2.1368 \times 10^{-4}] + 2.5182 = 61.49 \text{ hp}$$

and

$$C.E. = 23.52 \times 7.4809 = 175.95 \text{ hp}$$

Therefore:

$$\eta_T = \frac{61.49}{175.95} \times 100\% = 34.9\%$$

APPENDIX E

Volumetric Efficiency Calculations

$$\eta_v = \frac{\dot{m}\text{ act}}{\dot{m}\text{ theoretical}} \qquad (E_1)$$

$$\dot{m}_{Th} = \frac{\text{rpm} \times \rho_{air} \times \text{Displacement}}{2} \qquad (E_2)$$

Example: rpm = 600, $\dot{m}$ act = 79.5 $\frac{\text{lbm}}{\text{hr}}$

Solving E_2:

$$\dot{m}_{Th} = \frac{\left[600\left(\frac{1}{\text{min}}\right)\left(\frac{60\text{min}}{\text{hr}}\right)\right]\left[\frac{.072\text{ lbm}}{\text{ft}^3}\right]\left[(350\text{ in}^3)\left(\frac{\text{ft}}{12\text{ in}}\right)^3\right]}{2}$$

$$\dot{m}_{Th} = 262.5\ \frac{\text{lbm}}{\text{hr}}$$

Substituting into (E_1)

$$\eta_v = \frac{79.5\ \frac{\text{lbm}}{\text{hr}}}{262.5\ \frac{\text{lbm}}{\text{hr}}} = 30.3\%$$

Driveability Evaluation

Baseline Appendix F TABLE F-1

Calibration No. 11-24 19 81, 350 C.I.D. T.H.M. Transmission.

Program: Micro-Carburetor

VEHICLE INFO.		ENGINE INFO.		EMISSION INFO.			MISC. INFO.	
Vehicle Number: 4501		C.I.D.: 350		EGR Valve & Orifice: Yes			Date: 11/24/80	Temp: 70°
Model Year/Carline: 1973 Impala		Engine Number:		Transducer: Back-Pressure	Catalyst: G.M.		Wind: Light	Barometer:
Engine/Vehicle Miles: 85857		Calibration:		Thermactor: No	T.D.V.:		Location: JPL	
Transmission: THM350	Axle: 2.73	CARB. & DIST. INFO.		Vac. Amp.:	S.D.V.:		Road Condition: Clear and Dry	
Other:		Carb. Part No.: Rochester 2V	Curve No.:	49s: X	Calif.:	50s:	Jury Members: Merkel Weiss, Steve Mazor	
		Distributor Curve:	Initial: 6; R.P.M.: 500	Canada:				

Intermed. Eng. Temp. Idle		N/Dr.	Idle After Hiway Run		N/Dr.	Idle After Hot Soak		N/Dr.
7	Vac	18.5 / 14	6	Vac	19 / 14.5	10 min. Soak	Vac	17 / 13.5
	RPM			RPM			RPM	

The above components were evaluated by the Jury members indicated and received a rating of –

Component	S	M			Ave	After Hot Soak			
3rd Gear Crowds 20-30 MPH:	7	7			7				
Crowds 30-40 MPH:	7	7			7				
Crowds 40-50 MPH:	7	7			7				
3rd Gear Road Loads 20 MPH:	6	7			6.5				
Road Loads 30 MPH:	7	7			7				
Road loads 40 MPH:	6	7			6.5				
W.O.T. accel. 0 to 30 MPH:	7	8			7.5				
Part thro. accel. 0 to 30 MPH:	7	7			7				
Tip-in 0-30 MPH:	6	7			6.5				
Crowds above 50 MPH:	6	7			6.5				
Road loads above 50 MPH:	7	7			7				
Tip-in after hot soak:	6				6				
Hot start time. 1.8 Sec.									
Idle qual. inter. temp.:	6	6			6				
Idle qual. after hiway run:	7	7			7				
Idle qual. after hot soak:	6	5			5.5				
Thro. feel, travel, efforts:									

MILEAGE AT START	
MILEAGE AT FINISH	

Remarks

Slight hesitation WOT from stop.

VEHICLE EVALUATION RATING SYSTEM

Unacceptable				Border Line	Acceptable				
1	2	3	4	5	6	7	8	9	10
Production Reject									
Poor			Cust Comp	Border Line	Barely Accept	Fair	Good	Very Good	Excellent

Signatures:

Driveability Evaluation

Micro Carb Appendix F Table F-2

Calibration No. 1-23 1981, 350 C.I.D. T.H.M. Transmission.
Program Micro-Carburetor

VEHICLE INFO.		ENGINE INFO.		EMISSION INFO.		MISC. INFO.	
Vehicle Number: 4501		C.I.D.: 350		EGR Valve & Orifice: Yes		Date: 1/23/81	Temp: 70°
Model Year/Carline: 1973 Impala		Engine Number:		Transducer: Back-Pressure	Catalyst: G.M.	Wind: No	Barometer:
Engine/Vehicle Miles: 86082		Calibration:		Thermactor: No	T.D.V.:	Location: JPL	
Transmission: THM350	Axle: 2.73	CARB. & DIST. INFO.		Vac. Amp.:	S.D.V.:	Road Condition:	
Other:		Carb. Part No.: Micro-Carb	Curve No.:	49s: X / Calif.: / 50s:		Jury Members: Steve Mazor, Merkel Weiss	
		Distributor Curve:	Initial: 6 / R.P.M.: 500	Canada:			

Intermed. Eng Temp Idle		N/Dr	Idle After Hiway Run		N/Dr.	Idle After Hot Soak		N/Dr
Vac		13.5	Vac		14	Vac	17	13.5
RPM			RPM			RPM		

The above components were evaluated by the Jury members indicated and received a rating of –

	Remark	S	M			Ave	After Hot Soak			
Crowds 20-30 MPH	1	6-	7			6.3				
3rd Gear Crowds 30-40 MPH		7	7			7				
Crowds 40-50 MPH		7	7			7				
Road Loads 20 MPH		6	6			6				
3rd Gear Road Loads 30 MPH		7	7			7				
Road loads 40 MPH		6	6			6				
W.O.T. accel 0 to 30 MPH	2	5	5			5				
Part thro accel 0 to 30 MPH		7	7			7				
Tip-in 0-30 MPH		6	7			6.5				
Crowds above 50 MPH		7	7			7				
Road loads above 50 MPH		7	7			7				
Tip-in after hot soak		6				6				
Hot start time .8 Sec										
Idle qual inter temp		6	7			6.5				
Idle qual after hiway run	3	7	6			6.5				
Idle qual after hot soak		5				5				
Thro. feel, travel, efforts										

MILEAGE AT START	
MILEAGE AT FINISH	

Remarks

1. Light surge 14" and 20 mph.
2. Moderate hesitation 0-5 mph.
3. Slight regular lope.

VEHICLE EVALUATION RATING SYSTEM

Unacceptable				Border Line	Acceptable				
1	2	3	4	5	6	7	8	9	10
Production Reject									
Poor			Cust Comp	Border Line	Barely Accept	Fair	Good	Very Good	Excellent

Signatures

Vehicle Cold Starting and Driveaway Evaluation Tests

Test No.	Veh. No.	Starting Data		Cranking Data		This Data is Responsibility of Requester		
2	4501	Crank-speed		System Current		Carburetor: Roch. 2V	Dist.	Calibration No.:
Date: 10-28-80	Vehicle Make & Model: 1973 Impala	First-fire	1 sec	Batt. Volts		Model	Curve	Cal ☐ 495 ☒
Room Temp.	Vehicle Model Year: 1973	Eng-to-run	1.15sec	Start-volts		Flow No.	Dist. No.	PAS ☐ Development ☐
Batt. Temp.	Engine CID & No.: 350	Attempts	1	Coil Volts		Fast Idle:	Initial 6°	☒ Acceptable
Driver: S. Mazor	Trans.: THM-350	Soak Time	17 hr.	Batt. A.H.		Curb Idle: 600 rpm	@ 500 rpm	☐ Not Acceptable
Recorder: M. Weiss	Low Temp. 56°F	Soak Temp.		Starter Size		Throttle Modulator:		Signatures:
Observer:	Tests Since Last Oil Change:					Spark Modulator:		
Tire Press: 32 psi						Bi-metal		
						P/D & C/S	Dynamometer Settings	
						Torque	Inertia Weight:	
						Restriction	Load:	Windage:
						Test Fuel: Pump	Set By:	

Miles Odo.	Engine RPM	Vacuums: Man.	Vacuums: Dist.	Vacuums: EGR	Engine-Idle: Sat.	Engine-Idle: Load	Engine-Idle: Rough	Engine-Idle: Stall	Drive Accel.: Low Int. Man. Vac.	Drive Accel.: Sat.	Drive Accel.: Lean	Drive Accel.: Loading	Drive Accel.: Backfire	Drive Accel.: Stumbled	Drive Accel.: Stall	Drive Accel.: Hesit.	Road Load: Sat.	Road Load: Lean	Road Load: Chuckle	Temp (°F): Top Coolant	Temp (°F): Engine Oil	Temp (°F): Carb Inlet Air	Choke Off	Choke On	Remarks
N Hi Cam		19	16		X																				
N Pull Down																									
D Hi Cam		14	13				SL																		
D Pull Down																									
40-60 ft.		13.5	11				SL		13	X							X						X		
.2		11.5	0				SL		10	X							X								
.4		10.5	0				X		7	X							X								
.6		9.5	0				X		8	X							X								
.8		10	0				mod		3	X							X								
1.0		10	0				mod		10	X							X								
1.2		11	0				X		4	X							X								
1.4		11	0				SL		9	X							X								
1.6		11	0				SL		3	X							X								
1.8		12	0				SL		wot	X							X								
2.0		12	0				SL																		
2.2																									Tip in at:
2.4																									20 MPH OK
2.6																									25 MPH OK
2.8																									30 MPH OK
3.0																									

Vehicle Cold Starting and Driveaway Evaluation Tests APPENDIX F TABLE F-4

		Starting Data		Cranking Data	
Test No.: 3	Veh. No.: 4501	Crank-speed		System Current	
Date: 11-10-80	Vehicle Make & Model: Chevy Impala	First-fire		Batt. Volts	
Room Temp.: 71.5°	Vehicle Model Year: 1973	Eng-to-run	2.2 sec	Start-volts	
Batt. Temp.:	Engine CID & No.: 350	Attempts	1	Coil Volts	
Driver: J. Allison	Trans.: THM 350	Soak Time	18 hrs	Batt. A.H.	
Recorder: R. Hall	Low Temp. 50°F				
Observer:	Tests Since Last Oil Change:	Soak Temp.	60°F	Starter Size	
Tire Press: 40 PSI					

This Data is Responsibility of Requester

Carburetor: Roch. 2V	Dist.	Calibration No.:
Model	Curve	Cal ☐ 495 ☒
Flow No.	Dist. No.	PAS ☐ Development ☐
Fast Idle:	Initial 6°	☒ Acceptable
Curb Idle: 600 rpm	@ 500 rpm	☐ Not Acceptable
Throttle Modulator:		Signatures:
Spark Modulator:		
Bi-metal		
P/D & C/S	Dynamometer Settings	
Torque	Inertia Weight: 4000 lbs	
Restriction	Load: 12 Hp	Windage:
Test Fuel: Indolene	Set By: J. Allison	

Miles Odo.	Engine RPM	Vacuums: Man.	Vacuums: Dist.	Vacuums: EGR	Engine-Idle: Sat.	Engine-Idle: Load	Engine-Idle: Rough	Engine-Idle: Stall	Drive Accel.: Low Int. man. vac.	Drive Accel.: Sat.	Drive Accel.: Lean	Drive Accel.: Loading	Drive Accel.: Backfire	Drive Accel.: Stumble	Drive Accel.: Stall	Drive Accel.: Hesit.	Road Load: Sat.	Road Load: Lean	Road Load: Chuckles	Temp (°F): Top Coolant	Temp (°F): Engine Oil	Temp (°F): Carb Inlet Air	Choke Off	Choke On	Remarks
N Hi Cam		19.4	16.5		X																				
N Pull Down																									
D Hi Cam		14.25	13.25		X																				
D Pull Down																									
40-60 ft.		13	12.25		X					X								X							
.2		14	0				SL			X							X						X	X	
.4		13.75	0				SL			X							X								
.6		13.75	0				SL			X							X								
.8		13.5	0				SL			X							X								
1.0		13.5	0				SL			X							X								
1.2		13.25	0				SL			X							X								
1.4	700	13.5	0				SL			X							X								
1.6	700	13.5	0				SL			X							X								
1.8																									
2.0																									
2.2																									
2.4																									Tip in at:
2.6																									20 MPH OK
2.8																									25 MPH OK
3.0																									30 MPH OK

Vehicle Cold Starting and Driveaway Evaluation Tests

APPENDIX F TABLE F-5

Test No.: 4	Veh. No.: 4501
Date: 11-24-80	Vehicle Make & Model: Chevy Impala
Room Temp.:	Vehicle Model Year: 1973
Batt. Temp.:	Engine CID & No.: 350
Driver: S. Mazor	Trans.: THM-350
Recorder: M. Weiss	Low Temp.: 47°F
Observer:	Tests Since Last Oil Change:
Tire Press: 32 psi	

Starting Data		Cranking Data	
Crank-speed		System Current	
First-fire	1.8 sec	Batt. Volts	
Eng-to-run	1.8 sec	Start-volts	
Attempts	1	Coil Volts	
Soak Time		Batt. A.H.	
Soak Temp.	64°F	Starter Size	

This Data is Responsibility of Requester

Carburetor: Roch. 2V	Dist.	Calibration No.:
Model	Curve	Cal ☐ 495 ☒
Flow No.	Dist. No.	PAS ☐ Development ☐
Fast Idle:	Initial 6°	☒ Acceptable
Curb Idle: 600 rpm	@ 500 rpm	☐ Not Acceptable
Throttle Modulator:		Signatures:
Spark Modulator:		
Bi-metal		
P/D & C/S	Dynamometer Settings	
Torque	Inertia Weight:	
Restriction	Load:	Windage:
Test Fuel: Pump	Set By:	

Miles Odo.	Engine RPM	VACUUMS Man.	VACUUMS Dist.	VACUUMS EGR	ENGINE-IDLE Sat.	ENGINE-IDLE Lean	ENGINE-IDLE Rough	ENGINE-IDLE Stall	DRIVE ACCELERATION Low Int. man. vac.	DRIVE ACCELERATION Sat.	DRIVE ACCELERATION Lean	DRIVE ACCELERATION Loading	DRIVE ACCELERATION Backfire	DRIVE ACCELERATION Stumbling	DRIVE ACCELERATION Stall	DRIVE ACCELERATION Hesit.	ROAD LOAD Sat.	ROAD LOAD Lean	ROAD LOAD Chuckle	TEMP (°F) Top Coolant	TEMP (°F) Engine Oil	TEMP (°F) Carb Inlet Air	Choke Off	Choke On	Remarks
N Hi Cam		19.5	16	X																					
N Pull Down																									
D Hi Cam		14.5	13	X																					
D Pull Down																									
40-60 ft.		14.5	12	X					10	X															
.2		14.5	12	X					8	X							X								
.4		13	11	X					7	X							X								
.6		15	0	X					11	X							X						X	X	
.8		14.5	0	X					5	X							X								
1.0		14.5	0	X					9	X							X								
1.2		14.5	0	X					3	X							X								
1.4		14.5	0	X					wot	X							X								
1.6		14.0	0	X					12	X							X								
1.8		15	0	X					10	X							X								
2.0																	X								
2.2																									
2.4																									
2.6																									
2.8																									
3.0																									

Tip in at:
20 MPH OK
25 MPH OK
30 MPH OK

Vehicle Cold Starting and Driveaway Evaluation Tests

APPENDIX F TABLE F-6

		Starting Data		Cranking Data		This Data is Responsibility of Requester		
Test No.: 5	Veh. No.:	Crank-speed		System Current		Carburetor Micro-carb	Dist.	Calibration No.:
Date: 1-15-81	Vehicle Make & Model: 1973 Impala	First-fire	1 sec	Batt. Volts		Model	Curve	Cal ☐ 49S ☒
Room Temp.:	Vehicle Model Year: 1973	Eng-to-run	2 sec	Start-volts		Flow No.	Dist. No.	PAS ☐ Development ☐
Batt. Temp.:	Engine CID & No.: 350	Attempts	2	Coil Volts		Fast Idle:	Initial 6°	☐ Acceptable
Driver: S. Mazor	Trans: THM-350	Soak Time	17 hrs	Batt. A.H.		Curb Idle: 600 rpm	@ 500 rpm	☐ Not Acceptable
Recorder: M. Weiss	Low Temp. 48°F	Soak Temp.	60°F	Starter Size		Throttle Modulator:		Signatures:
Observer:	Tests Since Last Oil Change:					Spark Modulator:		
Tire Press:						Bi-metal		
						P/D & C/S .135	Dynamometer Settings	
						Torque	Inertia Weight:	
						Restriction	Load:	Windage:
						Test Fuel: Pump	Set By:	

Miles Odo.	Engine RPM	Vacuums: Man.	Vacuums: Dist.	Vacuums: EGR	Engine-Idle: Sat.	Engine-Idle: Lean	Engine-Idle: Rough	Engine-Idle: Stall	Drive Acceleration: Low int. man. vac.	Drive Acceleration: Sat.	Drive Acceleration: Lean	Drive Acceleration: Loading	Drive Acceleration: Backfire	Drive Acceleration: Stumbled	Drive Acceleration: Stall	Drive Acceleration: Hesit.	Road Load: Sat.	Road Load: Lean	Road Load: Chuckle	Temp (°F): Top Coolant	Temp (°F): Engine Oil	Temp (°F): Carb Inlet Air	Choke Off	Choke On	Remarks
N Hi Cam		17	17																						
N Pull Down																									
D Hi Cam								XX																	
D Pull Down																									
40-60 ft.		13.5	13.5		X					X															
.2		14.5	14.5				SL		15	X							X								
.4		14.5	14.5				SL		12	X							X								
.6		14	14				SL		8	X							X							X	
.8		14	14		X				7	X							X								
1.0		13.5	13.5				SL		4	X							X								
1.2		13	13				SL		6	X							X								
1.4		14	14				SL		wot						X		X								
1.6		14	14				SL		7	X							X								
1.8		14	14				SL		wot						X		X								
2.0		13	13				SL		13	X							X								
2.2		13	13.5		X		SL		3	X							X								
2.4									wot						X										Tip in at:
2.6									rol wot	X															20 MPH OK
2.8																									25 MPH OK
3.0																									30 MPH OK

Vehicle Cold Starting and Driveaway Evaluation Tests

		Starting Data		Cranking Data		This Data is Responsibility of Requester		
Test No. 6	Veh. No. 4501	Crank-speed		System Current		Carburetor Micro-carb	Dist.	Calibration No.:
Date 1-16-81	Vehicle Make & Model Chevy Impala	First-fire	2.1 sec	Batt. Volts		Model	Curve	Cal ☐ 49S ☒
Room Temp.	Vehicle Model Year 1973	Eng-to-run	11.1 sec	Start-volts		Flow No.	Dist. No.	PAS ☐ Development ☐
Batt. Temp.	Engine CID & No. 350	Attempts	5	Coil Volts		Fast Idle:	Initial 6°	☐ Acceptable
Driver: M. Weiss	Trans. THM-350	Soak Time	19 hrs	Batt. A.H.		Curb Idle: 600 rpm	@ 500 rpm	☐ Not Acceptable
Recorder: S. Mazor	Low Temp. 47°F	Soak Temp.	60°F	Starter Size		Throttle Modulator:		Signatures:
Observer:	Tests Since Last Oil Change:					Spark Modulator:		
Tire Press:						Bi-metal		
						P/D & C/S .135	Dynamometer Settings	
						Torque	Inertia Weight:	
						Restriction	Load:	Windage:
						Test Fuel: Pump	Set By:	

Miles Odo.	Engine RPM	Vacuums: Man.	Vacuums: Dist.	Vacuums: EGR	Engine-Idle: Sat.	Engine-Idle: Lead	Engine-Idle: Rough	Engine-Idle: Stall	Drive Acceleration: Low Inc. man. vac.	Drive Acceleration: Sat.	Drive Acceleration: Lean	Drive Acceleration: Loading	Drive Acceleration: Backfire	Drive Acceleration: Stumbled	Drive Acceleration: Stall	Drive Acceleration: Hesit.	Road Load: Sat.	Road Load: Lean	Road Load: Chuckles	Temp (°F): Top Coolant	Temp (°F): Engine Oil	Temp (°F): Carb Inlet Air	Choke Off	Choke On	Remarks
N Hi Cam							X																		
N Pull Down																									
D Hi Cam								XX																	
D Pull Down																									
40-60 ft.		14.3	14.6		X				10	X							X								
.2		15.5	15.8		X				12	X							X								
.4		14.5	15.0		X				9	X							X								
.6		14.2	14.6		X				8	X							X						X		
.8		14	14.5		X				12	X							X								
1.0		14	14.5		X				6	X							X								
1.2		14.5	14		X				wot						X		X								
1.4		14	14.5		X				3	X							X								
1.6		13.8	14.4		X				wot (1)						X	(X)	X								
1.8		14.6	15.2		X				2	X															
2.0		13.8	14.2		X				5	X															
2.2																									
2.4																									Tip in at:
2.6																									20 MPH OK
2.8																									25 MPH OK
3.0																									30 MPH OK

APPENDIX F
TABLE F-8
ANGULARITY EVALUATION FORM

Vehicle: Chevy Impala

Vehicle No: 4501

Mods: Baseline

Name: M. F. Weiss, S. D. Mazor

Date: November 24, 1981

Miles: 85857

DYNAMIC				STATIC			
Test	Max Lateral Accel. (ft/sec^2)	Idle Effects	Remarks	Test	Init. Idle Vac. ~(in Hg)	Final Idle Vac. ~(in Hg)	Remarks
Right Turn	22+	None	—	Front up 10°	19.25	18.4	Sl. Loading Rich
Left Turn	26	None	—	Back up 10°	17.5	17.0	Very Rough Lean
Forward Decel.	30	Stall	Immed. Stall	Right up 13°	18.0	17.4	Sl. Rough
Forward Decel.	25	None	—	Left up 11.5°	17.4	17.2	No Change
Forward Decel.	30	Stall	Immed. Stall	Front up 16°	19.2	18.8	Very Sl. Rough
Backward Decel.	18	None	—	Back up 16°	16 ± .5	16.5 ± .5	Sl. Rough Lean
Backward Decel.	16	None	—	Front up 1°	17.6 ± .2	17.2 ± .2	Level
Backward Decel.	16	None	—				
Forward Accel.	11	None	—				
Forward Accel.	14	None	—				
Forward Accel.	14	None	—				
Backward Accel.	10	None	—				
Backward Accel.	11	None	—				
Backward Accel.	11	None	—				

APPENDIX F

TABLE F-9

ANGULARITY EVALUATION FORM

Vehicle: Chevy Impala

Vehicle No: 4501

Mods: Micro-carburetor

Name: M. F. Weiss, S. D. Mazor

Date: January 13, 1981

Miles: 86115

DYNAMIC				STATIC			
Test	Max Lateral Accel. (ft/sec^2)	Idle Effects	Remarks	Test	Init. Idle Vac. ~(in Hg)	Final Idle Vac. ~(in Hg)	Remarks
Forward Decel.	29	None	—	Level 0°	18 ± .5	17.5 ± .5	Sl. Deterioration
Forward Decel.	27	None	—	Front up 10°	17.5 ± .5	16.5 ± .5	Mod. Deterioration
Backward Decel.	20	Nr. Stall	Spin out	Back up 13°	18.25 ± .25	16.5 ± .75	Sl. Deterioration
Backward Decel.	15	None	—	Front up 14.5°	17 ± .5	16.75 ± .5	Sl. Deterioration
Backward Decel.	18	None	—	Back up 17.5°	17.5 ± .25	19.75 ± 0	Major Increase in rpm
Forward Accel.	10	None	—	Right up 12°	18 ± .5	17 ± .25	No Deterioration
Forward Accel.	10	None	—	Left up 12°	17.25 ± .5	16.5 ± .5	Sl. Deterioration
Backward Accel.	11	None	—				
Backward Accel.	11	None	—				
Backward Accel.	11	None	—				
Left Turn	27	None	—				
Left Turn	29	None	—				
Left Turn	28	None	—				
Right Turn	31	None	—				
Right Turn	30	None	—				
Right Turn	31	None	—				
Right Turn	30	None	—				