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Evaluation of a Dresserator System Test Vehicle

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by

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Abstract

A test vehicle supplied by Dresser Industries was tested at the EPA Motor Vehicle Emission Laboratory to determine the feasibility of the Dresser Sonic Flow Carburetor system as applied to an 3-way catalyst system. The testing conducted included the standard Federal Testing Procedure, Highway Fuel Economy Testing, testing at 20°, 40°, 60°, and 70°F and sulfate testing. The test vehicle achieved emission levels below the 1981 and subsequent model year standards of .41 gm/mile hydrocarbon, 3.4 gm/mile carbon monoxide and 1.0 gm/mile NOx. The vehicle suffered starting problems at lower temperatures but had no driveability problems when warmed up. An extended idle period at the beginning of the cold start test procedure was also used at lower temperature. This modified FTP procedure improved driveability and lowered vehicle emissions somewhat.

Background

The EPA is interested in analyzing current automotive technology to determine the effects of such technology on emissions and fuel economy. The Dresserator System has been claimed to markedly reduce automobile emissions. Testing by several laboratories including Dresser, General Motors, and California Air Resources Board have substantiated these claims. Therefore, EPA requested that the prototype vehicle from Dresser Industries be made available for EPA testing at the EPA Motor Vehicle Emission Laboratory.

Test Procedure

A test plan was submitted by the Characterization Technology Assessment Branch for approval. The test plan calls for Clayton split-roll dynamometer testing using Federal Test Procedure (FTP), and the Highway Fuel Economy Test (HFET), and the Congested Freeway Driving Schedule (CFDS). The Clayton testing, was followed by controlled Environmental Test Chamber (CETC) testing at 20°, 40°, 60°, and 75°F and using both standard FTP and HFET sequences and an extended idle FTP sequence. The CETC uses a single roll Labeco dynamometer. The extended idle test involved was a standard FTP with 45 seconds of additional idle prior to the start of bag 1.

Device Description

A complete description of the Dresser Carburetor and Dresserator System including schematics and supporting test data was supplied by Dresser Industries. This information is also included in Attachment A. The Dresser information regarding a sonic EGR value was deleted since the vehicle tested by EPA did not have a sonic EGR valve.

Test Results

The test results are presented below:

Table One

Standard Federal Test Procedures on Clayton Dynamometer

Test Number	Date	HC (gram/mile)	CO (gram/mile)	NOx (gram/mile)	FTP miles per gallon
80-8112	3-10-81	.2394	1.889	.3136	13.482
80-8149	3-12-81	.2180	1.795	.3078	13.265

Table Two

Standard Highway Fuel Economy Test on Clayton Dynamometer

80-8113	3-10-80	.0169	.327	.0919	18.302
80-8150	3-10-80	.0180	.440	.1109	18.184

These results generally agree with the claims made about the Dresserator System and correlate with other data generated on this test vehicles. The FTP results show emission levels below the 1981 and subsequent model year standards for HC, CO, and NOx are quite easily achieved. It is important to note that this test vehicle is a large (4000#) vehicle with a large (350 CID) V-8 engine. It is our judgement that smaller vehicle engines combinations could utilize the same system and achieve equivalent emission results.

The vehicle was then transferred to the Controlled Environmental Test Chamber (CETC) for testing. It must be noted that the Dresserator System was not optimized for low temperature testing. Therefore, cold start testing problems were not unexpected.

The Dresserator vehicle with a standard FTP starting idle period would not run properly at 20°F. After two attempts at 20°F with over 6 stalls in the first 20 seconds, the decision to abort 20°F standard FTPs was made. The testing plan was modified to add 45 seconds to the initial idle period to hopefully prevent the stalling problem. The results of the standard FTP, extended idle FTP, and HFET tests are given below:

Table 3
Standard FTP in CETC

Test Number	Date	Hydrocarbon (gram/mile)	CO (gram/mile)	NOx (gram/mile)	Miles per gallon	Test Temperature	Number of Stalls
80-8195	3-24-81	.5624	4.092	.7588	13.351	28.0°F	2
80-8189	3-19-81	.2836	2.826	.5664	13.492	40.0°F	0
80-8191	3-23-81	.3005	3.258	.5296	13.214	40.0°F	1
80-8187	3-19-81	.2584	2.001	.4302	13.376	60.0°F	0
80-8205	3-30-81	.2548	2.875	.4330	14.002	60.0°F	0
80-8181	3-17-81	.2570	1.380	.3582	13.643	75.0°F	0
80-8183	3-17-81	.2640	1.221	.3228	13.841	75.0°F	0

Table 4
Extended Idle FTP in CETC

Test Number	Date	Hydrocarbon (gram/mile)	CO (gram/mile)	NOx (gram/mile)	Miles per gallon	Temperature	Test Stalls
80-8193	3-24-81	1.6927	8.098	.8996	12.722	20.0	10
80-8199	3-25-81	.8807	6.361	.7979	12.855	20.0	7
80-8200	3-25-81	.2787	1.770	.5674	13.422	40.0	0
80-8202	3-26-81	.4970	3.490	.4825	13.156	40.0	4
80-8445	3-31-81	.2033	2.345	.4195	14.206	60.0	0
80-8464	4-1-81	.2683	2.836	.3847	13.638	60.0	0
80-8463	3-31-81	.2570	1.678	.3467	13.447	75.0	1

Table 5
Highway Fuel Economy Test in CETC

Test Number of Number	Date	Hydrocarbon (gram/mile)	CO (gram/mile)	NOx (gram/mile)	Miles per gallon	Temperature	Test Stalls
80-8194	3-24-81	.0262	.534	.1870	18.480	20.0	0
80-8196	3-25-81	.0281	.478	.1569	18.753	20.0	0
80-8192	3-25-81	.0297	.659	.1924	18.506	40.0	0
80-8201*	3-25-81	.0475	1.180	.1558	19.028	40.0	1
80-8190	3-19-81	.0316	.796	.1588	18.735	42.0	0
80-8186	3-19-81	.0228	.489	.1684	18.636	60.0	0
80-8188	3-18-81	.0255	.360	.1230	18.720	60.0	0
80-8203	3-30-81	.0181	.393	.1516	18.881	60.0	0
80-8454	3-31-81	.0157	.425	.1235	18.721	60.0	0
80-8182	3-17-81	.0231	.353	.1026	18.410	73.0	0
80-8184	3-18-81	.0188	.400	.1079	18.682	75.0	0

*Vehicle lost power and stalled at 200 secs into sample bag. No reason was found.

As can be seen from the data, the low temperature cold-start stalling problems caused high variability in HC and CO emissions. This was not unexpected. The data shows a direct correlation between the number of stalls and the HC and CO readings. The temperature data indicate that HC, CO, and NOx rise as the temperature is reduced. This trend is consistent with other ambient temperature studies run in the CETC.

It is interesting to note that the extended idle FTP data is not significantly different than the standard FTP data. The extended idle did not noticeably reduce emissions or improve fuel economy. This comparison is probably masked by the stalling problem so numerical comparison would not be realistic.

The sulfate samples taken during the CFDS tests have not yet been analyzed. The necessary equipment to make the analysis is under repair.

When repairs are completed, the sulfate data will be tabulated. Copies of the sulfate data will be available from the TEB secretary.

Conclusions

The Dresserator System performed according to the claims made about it on the test vehicle supplied. The low temperature driveability problems must be addressed before such a system is put into production.

INTRODUCTION

The Dresserator Inductor system on a 1977 Chevrolet Nova has now met the statutory standards of 0.41 HC, 3.4 CO, and 0.4 NOx, while simultaneously providing an economy increase of about 5% over the base car. The addition of another Dresser development added an additional 5% economy increase at these low emission levels for a total of 10% over the base car. The Dresserator Inductor system is simple and commercially producible; it has a cost advantage over other systems designed to operate at low NOx levels. The present system utilizes a single three-way catalyst with no air pump or oxidation cleanup catalyst.

It is anticipated that the system can operate at the 1 gpm NOx level of the 1981 standards without the necessity of EGR, providing a further cost benefit. A vastly simplified version of the overall system has considerable economic advantage in operation at still higher NOx levels, as encountered in Europe. Under these conditions, the system is operated lean with a considerable (10-20%) increase in economy over the base car.

The heart of the Dresserator Inductor system is the Inductor itself, a variable critical-flow venturi. The design of the venturi enables it to maintain sonic velocity at its throat over most of the driving range of the car. ~~Under~~ these conditions, it can control mass flow and is an excellent atomizer. The mass flow control capability of the Inductor is used by Dresser in a variety of valve designs, one of which is a sonic EGR control valve which enables one to have a simple programmable EGR system. The atomization feature is utilized when the sonic principle is used as a carburetor. Here, fuel is added above the throat and excellent atomization is achieved as the fuel passes through the sonic throat. Since all of the air and all of the fuel pass through this throat, mixing is inherently very good. Many atomizers do well under steady-state conditions but it is this ability to atomize and mix well under all conditions that separates the Dresserator Inductor from the pack and permits attainment of these unique results.

Although not used in the current Dresserator Inductor system because of time constraints on our development program, the mass flow control capability can be utilized to further simplify the electronic control system since throat opening is a direct measure of mass flow to the engine. In addition, the mass-flow control of the sonic EGR valve can be incorporated to provide a simple, yet highly sophisticated system of engine control.

This report describes the Inductor system used and the results obtained with the 1977 Chevrolet Nova equipped with a 350 in^3 engine. The general principles of the Dresserator Inductor are described and comparisons made with competitive systems. In addition, the advanced Dresserator system is also discussed.

TECHNICAL DEVELOPMENT AND RESULTS

The Concept

The heart of the Dresserator Inductor system is the Inductor itself. It is a variable critical-flow venturi. By critical flow, one means that the velocity at the throat is sonic at which point the mass flow cannot be exceeded provided the upstream conditions of the flow remain the same. Variations which occur downstream, or in this case in the intake manifold, have no affect on flow through the throat, provided sonic velocity is maintained. The ability to maintain sonic velocity at the throat over a wide range of manifold vacuums is the unique feature of the Dresserator Inductor. This ability is accomplished through the utilization of a diffuser below the throat which converts the high velocity flow energy to pressure. By proper design, one can achieve high energy recoveries in the diffuser which allows operation from high vacuum to the range of 3 to 4 inches of manifold vacuum, while maintaining sonic flow at the throat over the full flow demand of the engine.

Figure 2 shows that a critical-flow venturi consists of an entrance zone which is subsonic, the throat which is sonic, and, depending on manifold vacuum, a supersonic zone followed by the subsonic zone. At high manifold vacuum, this supersonic zone can be quite significant, extending for an inch or more below the throat. This supersonic zone usually ends in a shock after which the flow is diffused for the remainder of the length of the diffuser. Under these conditions, energy recovery is not important since the unit is operating as a throttle with a significant pressure differential. As the pressure differential decreases, the supersonic zone shortens until the shock reaches the throat at which point, if the pressure differential continues to decrease, the system can no longer maintain sonic velocity and the throat

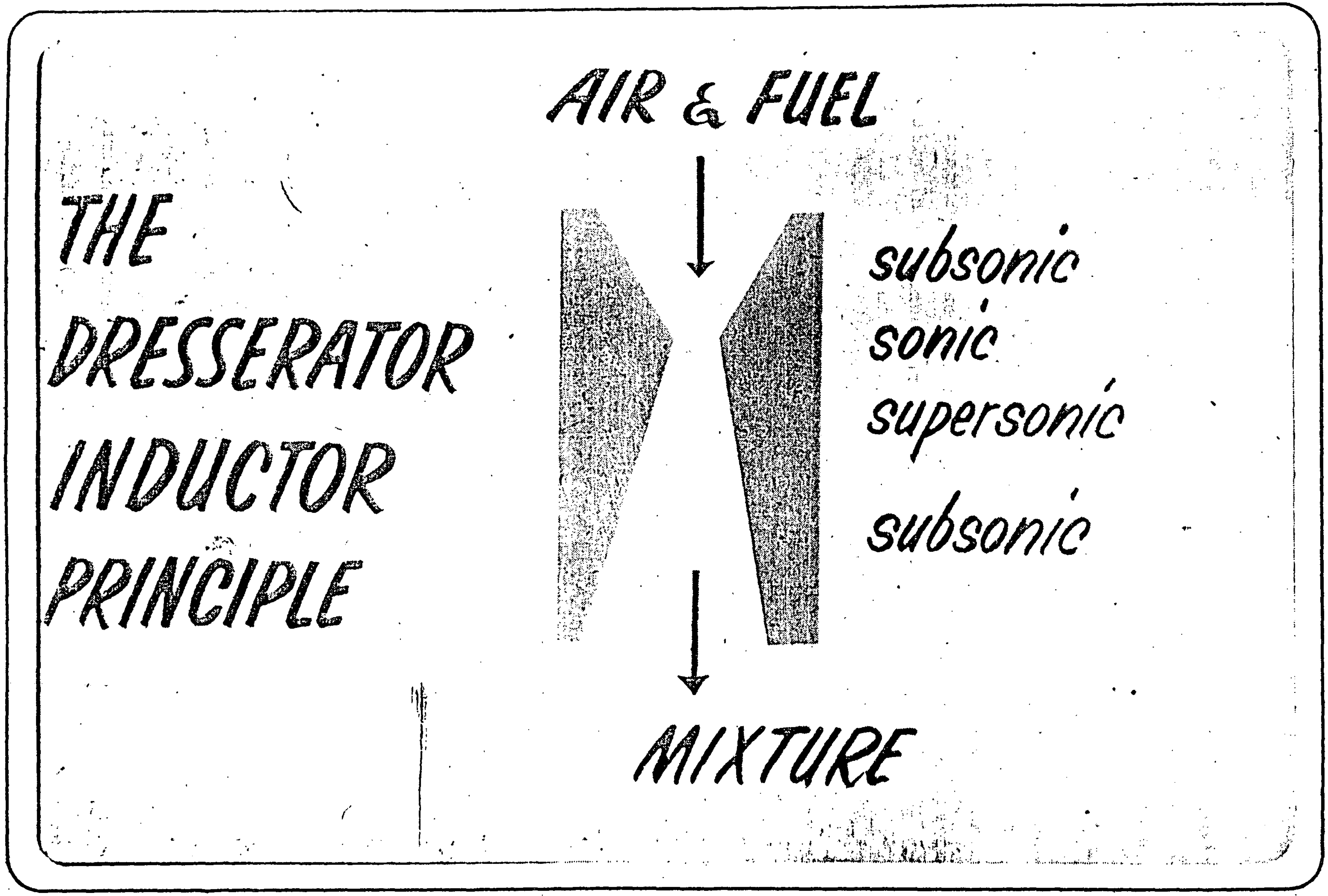

THE DRESSERATOR INDUCTOR PRINCIPLE
AIR & FUEL
subsonic
sonic
supersonic
subsonic
MIXTURE

Figure 2.

becomes subsonic and the system behaves as a modulatable, subsonic venturi. In the case of the Dresserator Inductor, the diffuser functions to recover energy from the high velocity flow stream such that as the pressure differential decreases, the system remains sonic even at very low pressure differentials.

Sonic velocity under ordinary conditions at the throat is around 1100 fps. This velocity can be utilized to create a very large shear force on fuel particles as they pass through the throat and cause the particles to break up into minute droplets generally in the range of 10 micron average size. We have found that it is important that the fuel be predistributed across the entire throat area in order to optimize the atomization. If this is not done, the particle size produced is much larger than 10 micron average and, indeed, can be quite non-uniform. Various predictive equations on atomization confirm the approximate average particle size that would be achieved with this kind of velocity and proper fuel distribution. Work by Stanford Research Institute on some of our earlier atomizers also confirmed this average particle size. More recent work on the Dresserator principle by British Leyland using very advanced particle size measuring techniques indicates an average particle size of 6 microns for the Dresserator Inductor. This average particle size is maintained constant down to the range of one inch of manifold vacuum before the effect of the lowered velocity of the throat is felt and the particle size begins to increase. Furthermore, British Leyland has confirmed our evidence that less fuel is on the manifold walls with sonic carburetion.

We have tested many atomizers and compared results with those from the Inductor. In laboratory atomization tests, the Inductor was always found to be superior. On the car at steady-state conditions, it is often difficult to choose among good atomizers. However, the ability of the Inductor to control atomization over most of the manifold vacuum range and to mix the fuel well with the air provides the significant differences that lead to the unique results obtained. When compared to other carburetion systems, we have generally seen lower NOx and when running in the lean-burn mode this can be as much as 50% lower. We always see lower CO by as much as two-thirds.

Advantages of the Concept

Sonic carburetion has two important principles, which differ from other types of carburetion. These are -

- mass flow control
- atomization control

When these two principles are properly applied, one then achieves the benefits of sonic carburetion. These benefits are -

- excellent cylinder-to-cylinder distribution
- excellent cycle-by-cycle distribution
- lean cold start capability
- improved economy
- excellent air/fuel ratio control

Under most of the operating conditions encountered in the CVS cycle, the Dresserator Inductor system on the 1977 Chevrolet led to a cylinder-to-cylinder distribution spread of only a few tenths of an air-fuel ratio. Under conditions where the system would become subsonic, this spread would increase to the range of one air-fuel ratio and only under wide-open throttle conditions at low RPM did it exceed one air-fuel ratio.

Cycle-by-cycle distribution is one of the features that we feel has major significance when one is concerned with operating at stoichiometric with a three-way catalyst. Since the sonic carburetor is an excellent pulsation dampener, its pulse-free charge provides excellent cycle-by-cycle air-fuel ratio control. This we determine by following the break point of the carbon monoxide emissions from individual cylinders as the engine goes from a lean condition towards stoichiometric. In general, we approach quite close to 15:1 A/F ratio before the carbon monoxide will begin to rise. Whereas, with other carburetion systems we have examined, this break point will occur at a much higher air-fuel ratio, indicating that the individual cylinder charging is quite variable. This can be observed even under conditions where one is measuring excellent cylinder-to-cylinder distribution.

We have long recognized the importance of our cold start capability which is brought about by the excellent atomization that is achieved. Since the average fuel particles are quite small, more of the gasoline travels through the cylinders in the air stream than with other carburetion systems which require extensive choking for enrichment in order to achieve volatility of a fraction of the fuel which then goes in a vaporized form into the cylinders. This is a major reason for the control of carbon monoxide emissions which has been recognized by others testing sonic carburetion.

Under all conditions and with all cars we have examined, we have always observed an improvement of fuel economy over the base car. In some cases, this has been as high as 30%; however, in those extreme cases, we must readily admit that a part of the reason was a very poor carburetion and induction system design of the base car. However, even in comparison with some of the best designed systems, we achieve a significant improvement.

Figure 3 shows a comparison of the attributes of a carburetor and a Dresserator sonic system. As can be seen, the Dresserator Inductor has a mass flow metering capability, is an excellent

CARBURETOR-DRESSERATOR FUNCTIONAL COMPARISON

	CARBURETOR	DRESSERATOR
MASS FLOW CONTROL	NONE	YES
ATOMIZER	POOR	EXCELLENT
MIXER	POOR	EXCELLENT

Figure 3

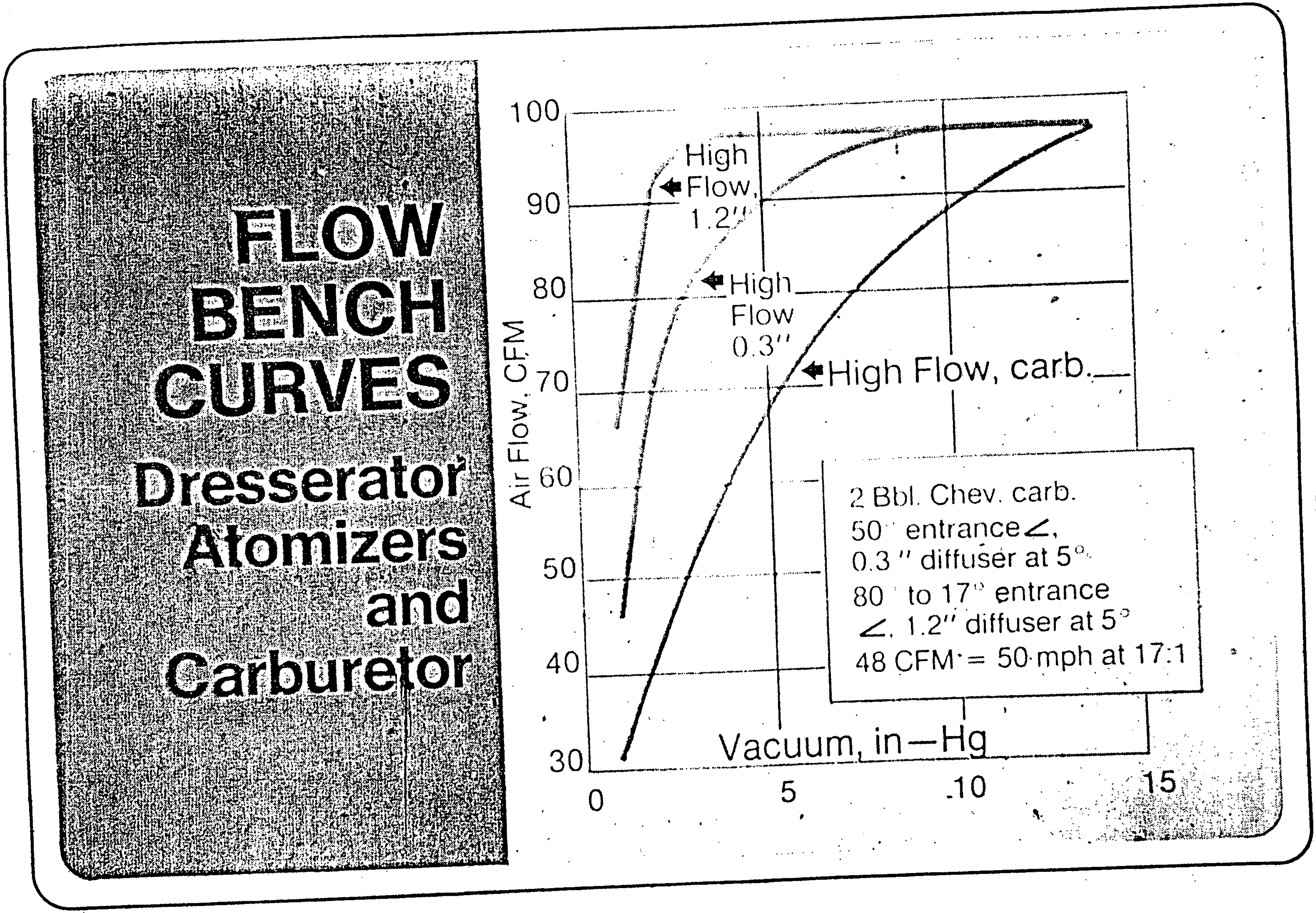
atomizer, and an excellent mixer; whereas, a carburetor provides only good atomization at high manifold vacuum conditions and is inherently a poor mixer since it utilizes a butterfly which divides the flow between a fuel-air stream and an air stream.

Figure 4 shows the comparison of the flow characterisitcs a carburetor and the Dresserator Inductor plotting manifold vacuum versus air flow. Each curve represents the point at which the system can maintain sonic velocity in its throat. Thus, all manifold conditions above the lines would indicate where the system is sonic and below that where it is subsonic. As one can see with the properly designed Dresserator Inductor, the system maintains sonic velocity over almost the whole manifold vacuum range.

Figure 5 shows a Dresserator Inductor test fixture operating on an engine dynamometer. This fixture was used to study fuel presentation to the throat for proper atomization. As can be seen through the plastic side of the unit, the throat is filled with a cloud of finely atomized fuel.

Application of the Concept

The Dresserator principle can be utilized in a variety of geometric shapes. A Model I has an annular throat containing a moveable pintle which modulates the throat area. This is shown in Figure 6. The diffuser is the annular space between the pintle and the throttle body wall. This geometry is excellent for use as a valve. It has some limitations when adapted as a carburetion system, one of these being a problem of idle fuel distribution around the very large periphery of the throat. This peripheral distance can be in the range of seven inches on our larger units. In addition, the top-opener as shown here, has limitations on the flow range that it can handle and still



FLOW BENCH CURVES
Dresserator Atomizers and Carburetor
Air Flow, CFM
Vacuum, in—Hg
100
90
80
70
60
50
40
30
0
5
10
15
High Flow, 1.2″
High Flow 0.3″
High Flow, carb.
2 Bbl. Chev. carb.
50° entrance ∠,
0.3″ diffuser at 5°
80° to 17° entrance
∠, 1.2″ diffuser at 5°
48 CFM = 50 mph at 17:1

Figure 4

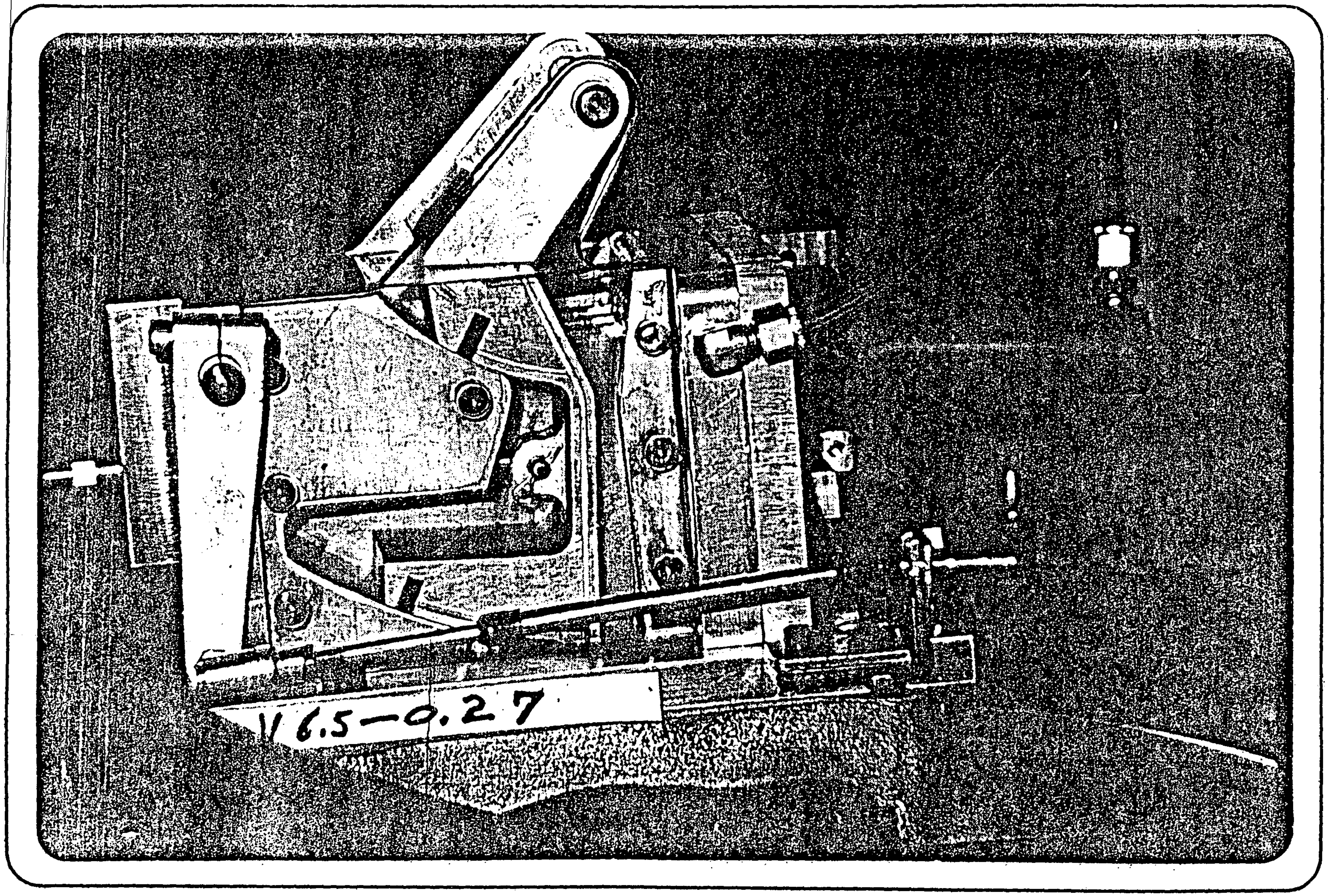


Figure 5

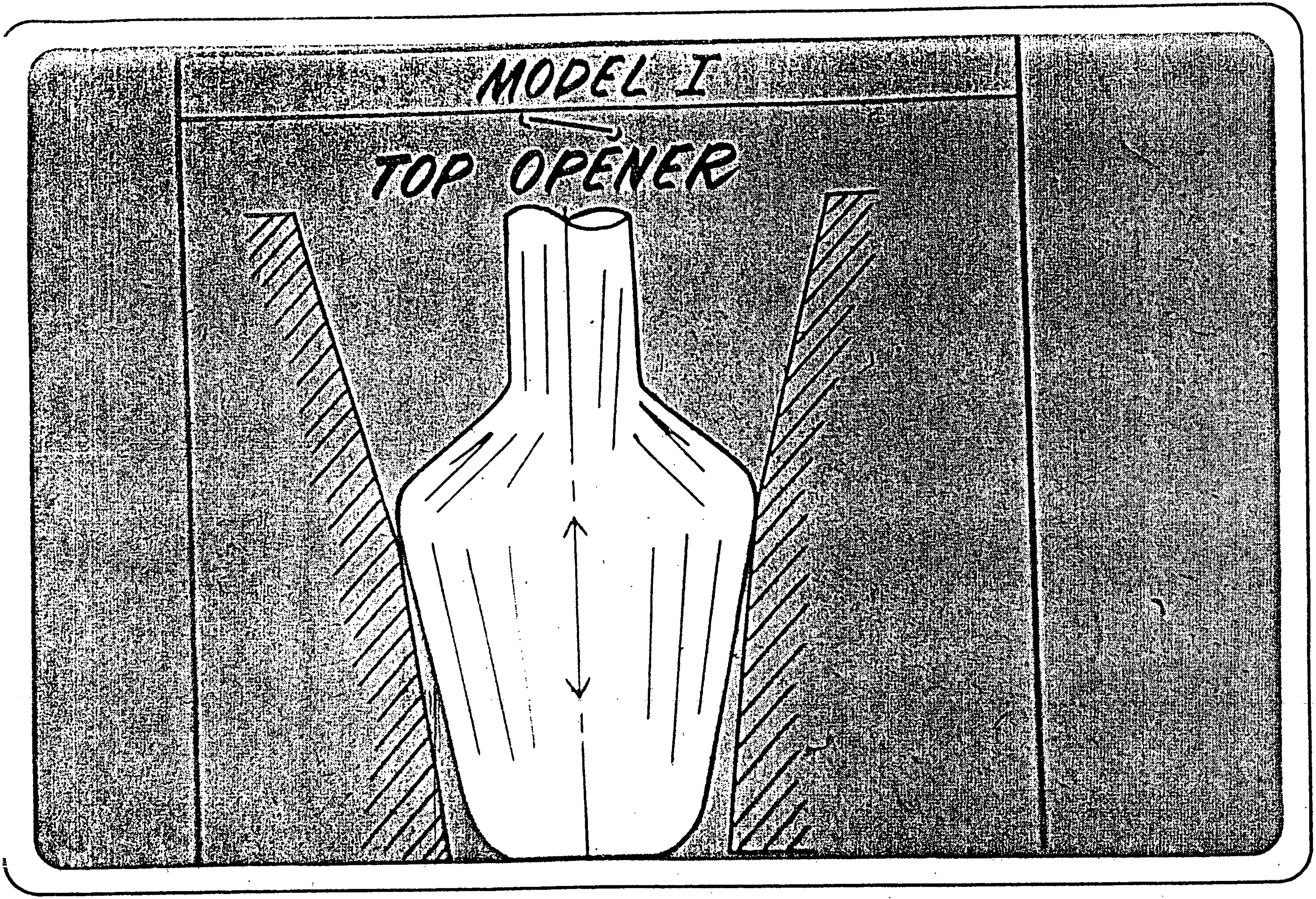


Figure 6

maintain sonic velocity. It can be designed efficient at the full open range, or the low-flow range, but does not have the turndown capability with efficient energy recovery of other models. A variety of the Model I involves an inverted system that we call a bottom-opener in which the throat is located at the smallest end of the pintle. The flow diverges out through the diffuser as opposed to the converging shape of the flow path of the top-opener. Characteristics of the bottom-opener are an *improved idle fuel distribution and a vastly improved turndown* ratio. The Model I bottom-opener is excellent as a valve and is our preferred geometry for a sonic EGR valve.

Figure 7 shows a rectangular shaped unit that we call a Model II. It consists of two shaped jaws which can be modulated by sliding apart or by pivoting around a top pivot point. The latter variant is the model used on the Chevrolet Nova. Fuel is distributed to this model through a fuel bar placed in the entrance. The unit has an excellent control over the area ratio of the diffuser and, thus, has a wide range efficiency with good idle fuel control.

A second rectangular model is shown in Figure 8. It is called a Model III and utilizes two fixed jaws with a slide in between to modulate the throat. This unit has excellent idle fuel control capability as well as an excellent turndown ratio. It has another quite unique feature: if the entrance slider wall and its opposite face are kept parallel, the unit has a constant area ratio in the entrance and, therefore, as long as the throat is sonic, it has constant depression at any point in the entrance zone providing an inherent constant depression metering capability.

These various Inductor models can be mated to a variety of metering systems. These include:

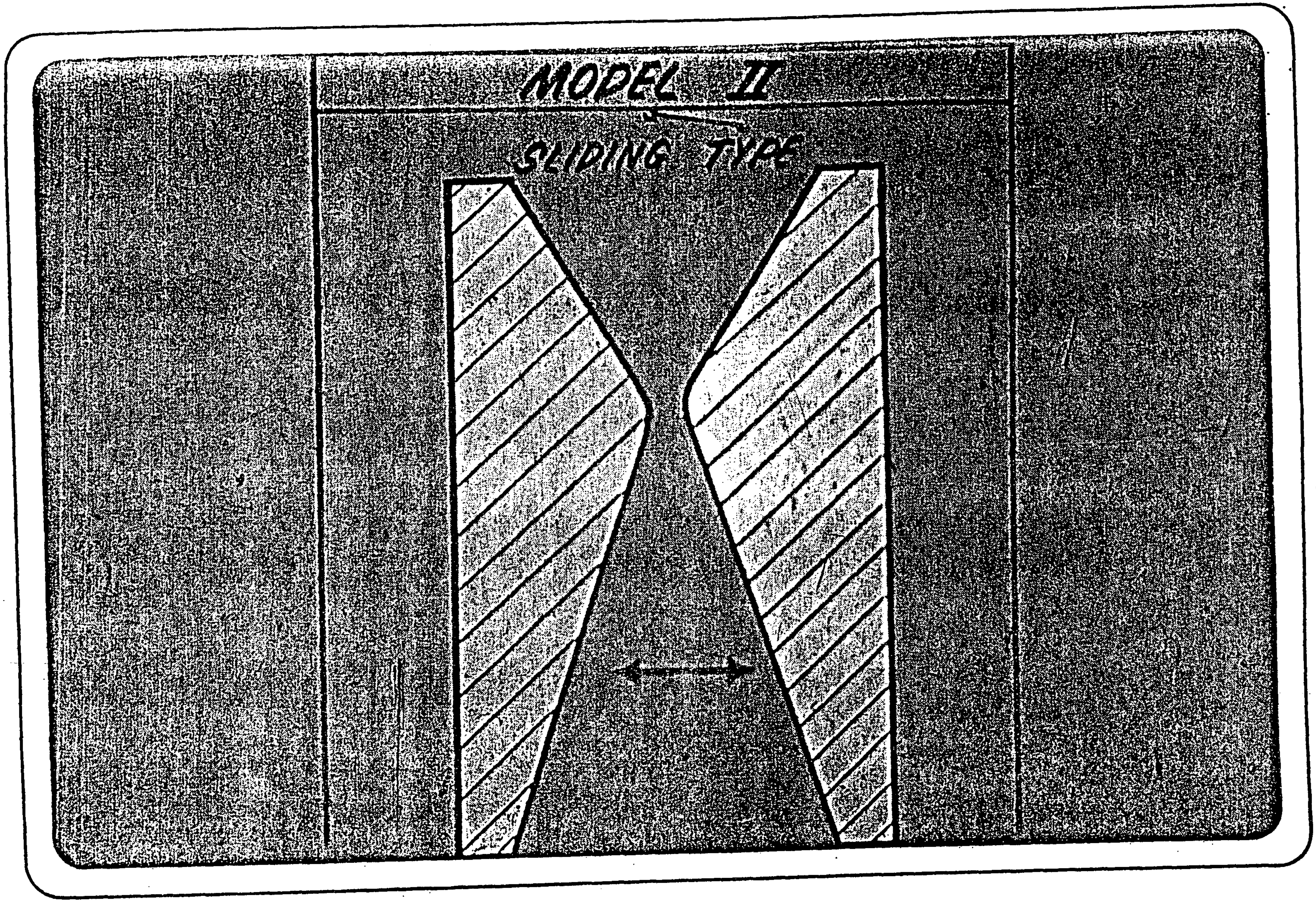


Figure 7

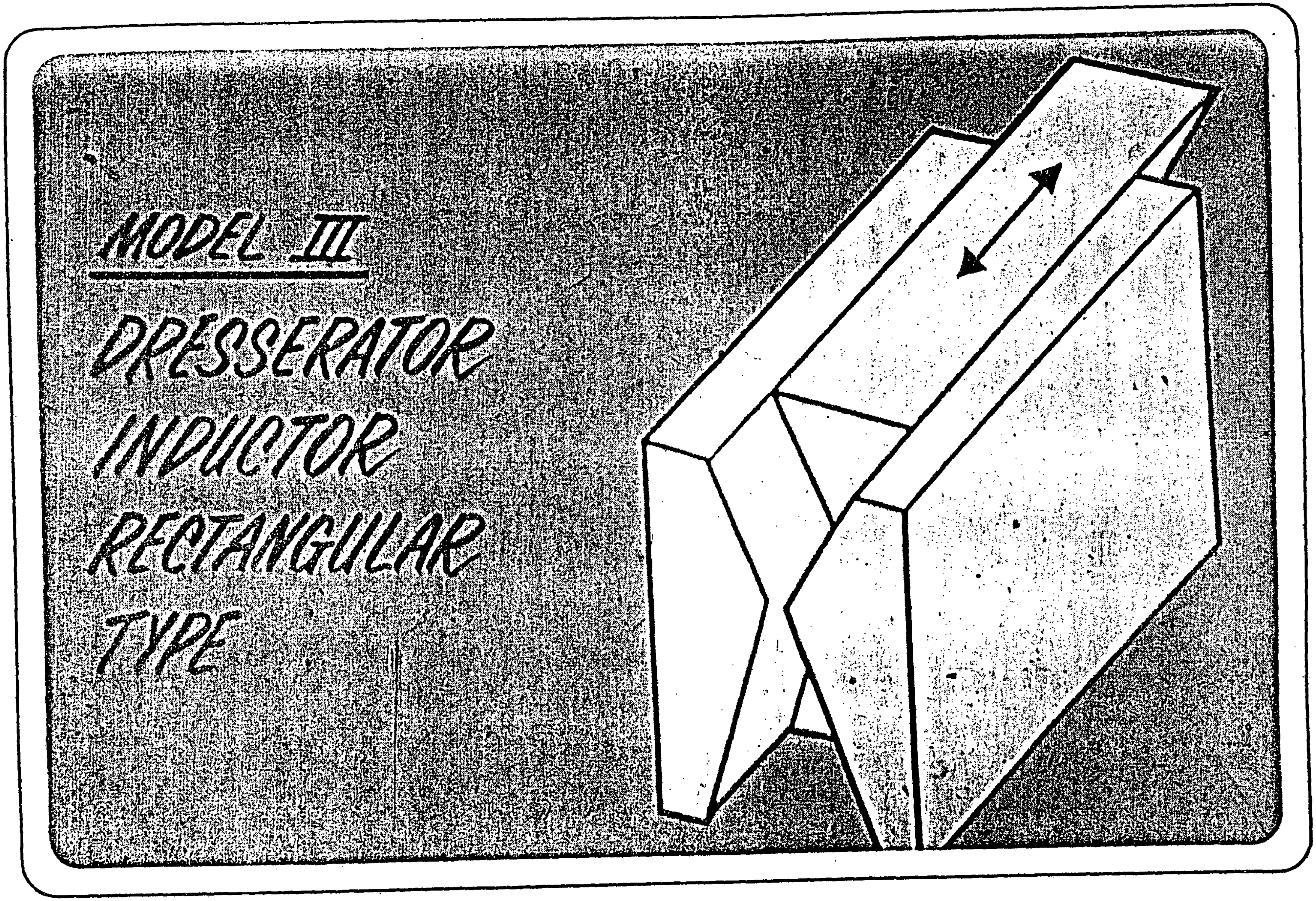


Figure 8

- float fed
- float fed (constant depression)
- electronic float fed
- electronic pressure fed
  - ΔP control
  - speed density
  - sonic mass flow

Any of the geometries can be mated with either float-fed or pressure-fed metering systems. However, it has been our experience that some of these have attributes more adaptable to one system than another. If one were to build a float-fed Dresserator Inductor, we would recommend the Model III, using its inherent constant depression for the metering. This is the choice of British Leyland. For a pressure-fed system, we prefer the Model II since it is a simpler throttle body.

The Model II System

The system used on the 1977 Chevrolet Nova is a pivoting jaw, Model II Inductor with speed density controlled fuel metering through the use of two fuel injectors feeding fuel above the throat through a fuel bar. The Inductor system is shown in Figure 9. This unit is a culmination of a considerable amount of research and design effort and is an improvement over the Model II pivoting jaw system as developed by the Ford Motor Company. Ford designed and built their pivoting jaw sonic carburetor with design features contrary to Dresser design criteria. These features were:

- fuel injection below the throat
- no fuel pre-distribution
- unstable diffuser design (stall)
- high exit velocity - mixture impaction

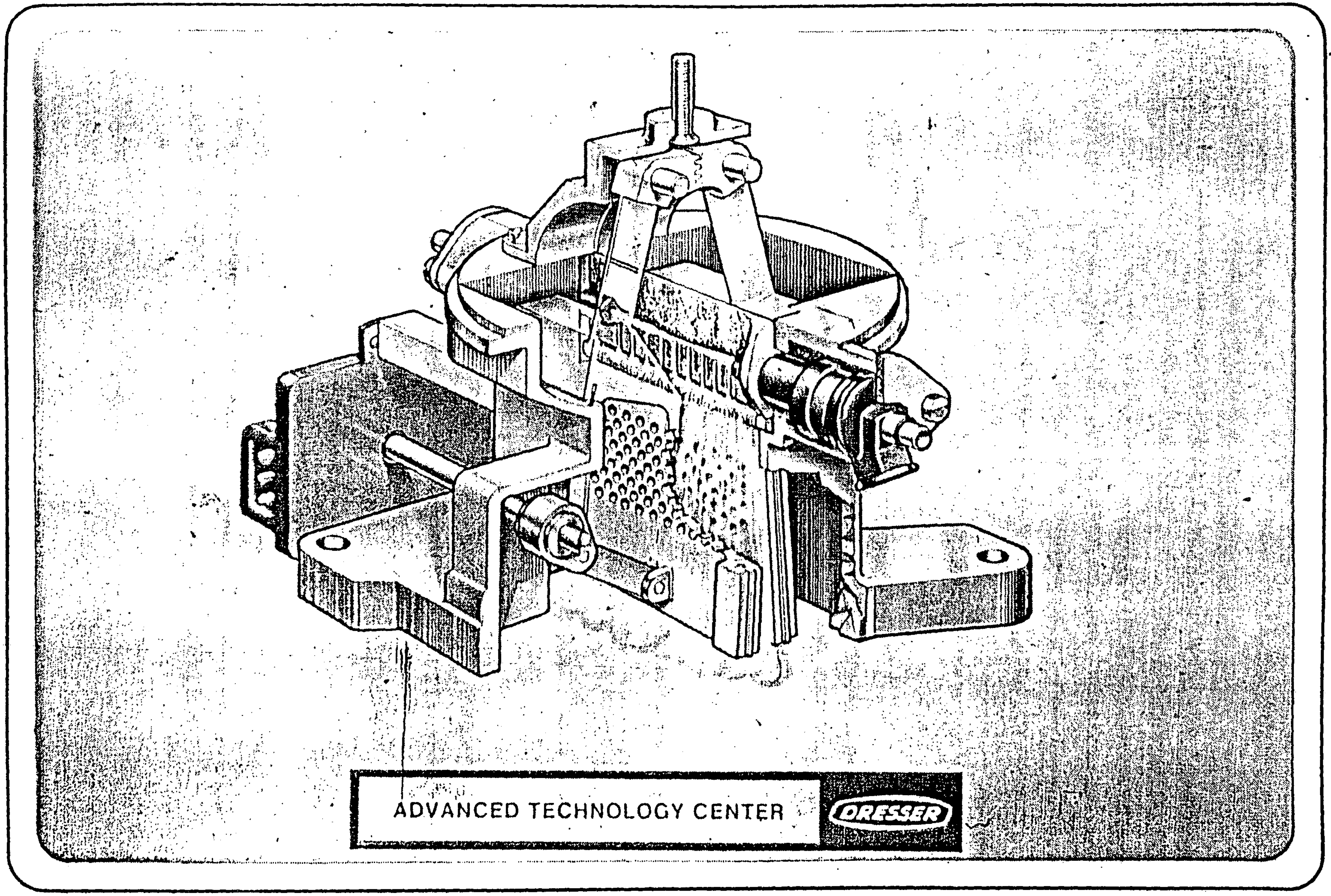


Figure 9

- a noticeable foot effort
- poor atomization control at wide-open throttle

By introducing fuel below the throat and without pre-distribution, the atomizing capability of the Inductor is not utilized. The diffuser design was such that it had flow instabilities and a high exit velocity which lead to mixture impaction on the manifold floor. We have found this to result in high NOx and reduced fuel economy. The particular diffuser design also resulted in a noticeable foot effort when coming off a deceleration and going back onto the throttle. In addition, the throat width required a throat opening for wide-open throttle which had a very poor atomization control in this mode.

Despite these problems, in contest with other systems at the 1 gpm NOx level with three-way catalyst equipped cars, Ford obtained better driveability with equivalent emissions and economy results than with the others examined, namely with a feedback carburetor and with electronic fuel injection. Dresser modifications to the Ford system showed a potential economy gain of greater than 10%.

The Dresser designed system as shown in Figure 9, incorporates the following design refinements:

- pulse-dampened fuel metering
- fuel introduction above throat
- increased width and decreased throat opening
- designed out of stall (stable flow)
- no foot resistance and simplified sealing
- low exit velocity

As can be seen in Figure 9, fuel is metered through two fuel injectors feeding opposite sides of a fuel bar shown in the cut-away. The fuel passages of this fuel bar produce a dampening of the pulses inherent in a fuel injector. The fuel proceeds through the downcomers and is pre-distributed across the throat by a threaded bar place below the downcomer. Fuel is then atomized as it passes through the throat and the diffuser. The diffuser incorporates a new design concept: the diffuser is porous, incorporating a series of holes in each jaw. These have the function to prevent the supersonic zone from extending further down the throat than the top row of holes. As the supersonic zone attempts to come down, it creates a high vacuum which causes flow from the back side of the jaws into the diffuser, leading in time to the supersonic flow shocking back to subsonic flow for the remainder of the diffuser. Since the shock and supersonic zone is kept high in the throat, there is no tendency for flow separation. Flow stability is obtained in the basic design as can be seen in Figure 10 which is one of our design charts that we have for each of our different models. Shown on this design chart are iso-unchoke points or vacuums at which level the system becomes subsonic. The ratio of the throat opening to diffuser length is plotted on the abscissa and the included angle of the diffuser is plotted on the ordinate. This angle increases as the diffuser opens since the system is pivoted from the top. The graph also contains two lines, one labeled "no-stall" and the other "developed stall". These are obtained from an adaption of Dr. Kline's work at Stanford University which shows that a diffuser designed below these lines is very stable but a diffuser designed above the lines is unstable. Design between the lines can have flow switching and recirculation, if provoked by foreign bodies such as by introduction of fuel below the throat or by tubes extending into the throat, as is the case with the

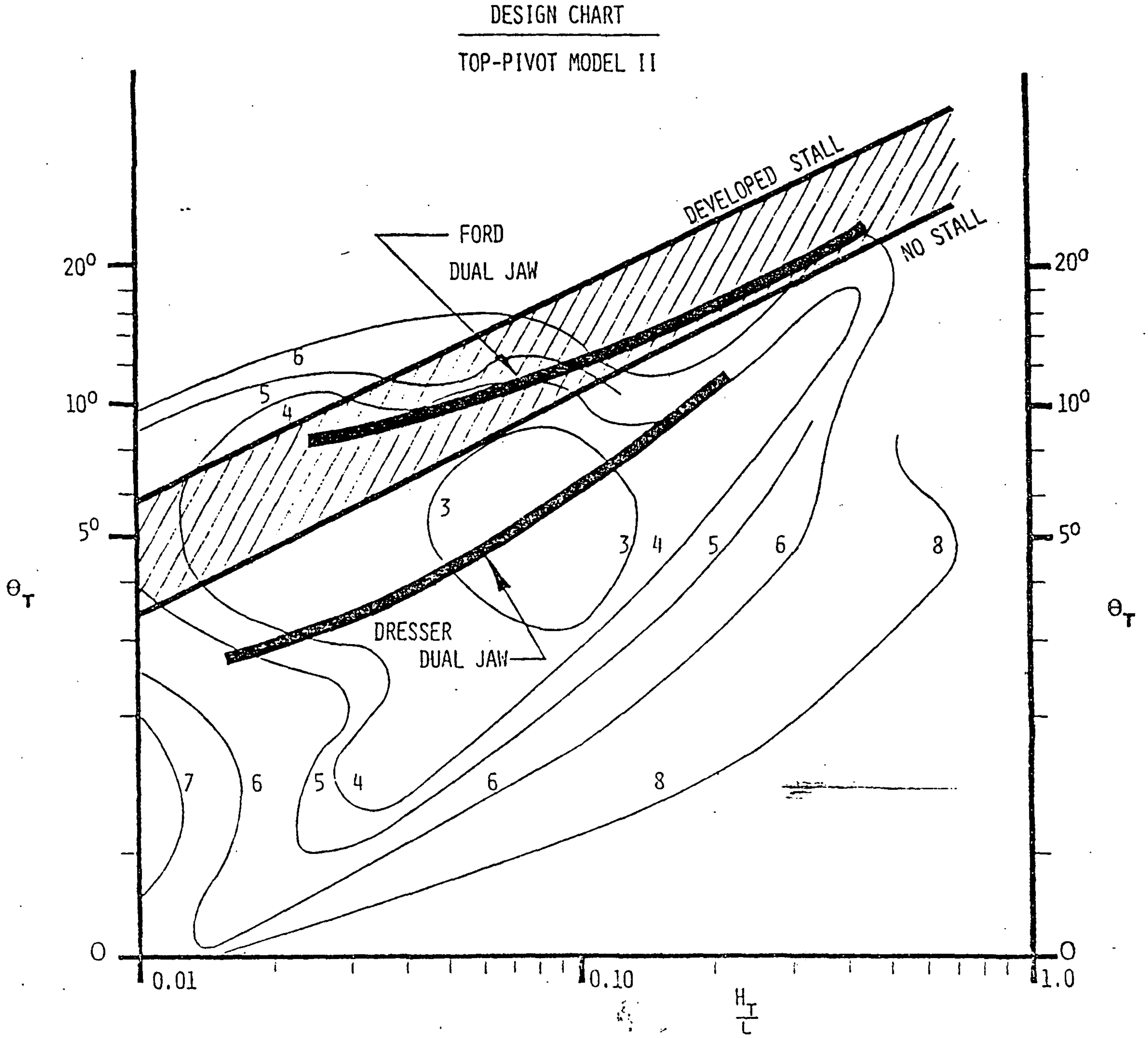

DESIGN CHART
TOP-PIVOT MODEL II
DEVELOPED STALL
NO STALL
FORD
DUAL JAW
DRESSER
DUAL JAW
20°
10°
5°
0
θ_T
0.01
0.10
1.0
$\frac{H_T}{L}$
3
4
5
6
7
8

Figure 10

Ford design. The dark line labeled "Ford dual-jaw" is an operating line showing where that design was located. The line labeled "Dresser dual-jaw" is the design used on the Chevrolet and is laid out to maximize the energy recovery as shown by the iso-unchoke lines and yet maintain a high stability.

The holes introduced in the jaw eliminates the cause of foot resistance by preventing a high vacuum zone from being created in the diffuser. By purposely causing leakage between the front and back of the diffuser, sealing is only required through the throat zone and on the back side of the jaws and need not extend below the top holes. The prevention of the supersonic zone from extending too far into the diffuser also prevents the jetting of a high velocity flow from the diffuser and thereby gives a very low exit velocity with the diffuser running full.

The metering system used with the Model II Dresserator Inductor is a speed density controlled, dual injector, single-point injection system. Two injectors feed fuel above the throat of the Dresserator Inductor. The Inductor is mounted on a single-plane manifold and no changes have been made to the engine or to the spark and EGR regimes. The fuel control system is shown schematically in Figure 11. It incorporates several components from the Cadillac fuel injection system: namely, the fuel pump regulator injector nozzles, as well as manifold pressure, air temperature, water temperature, and throttle position sensors. We utilize a different crankshaft position sensor than on the Cadillac since this is an experimental system and we wished to be able to study injector timing. Injector timing, however, was found not to have any significance in this system.

The electronic control unit is shown schematically in Figure 12 and is of our own design and fabricated in our laboratory. It is a straightforward speed density system used in

MODEL II - III -- FUEL CONTROL SYSTEM -- FUEL INJECTION

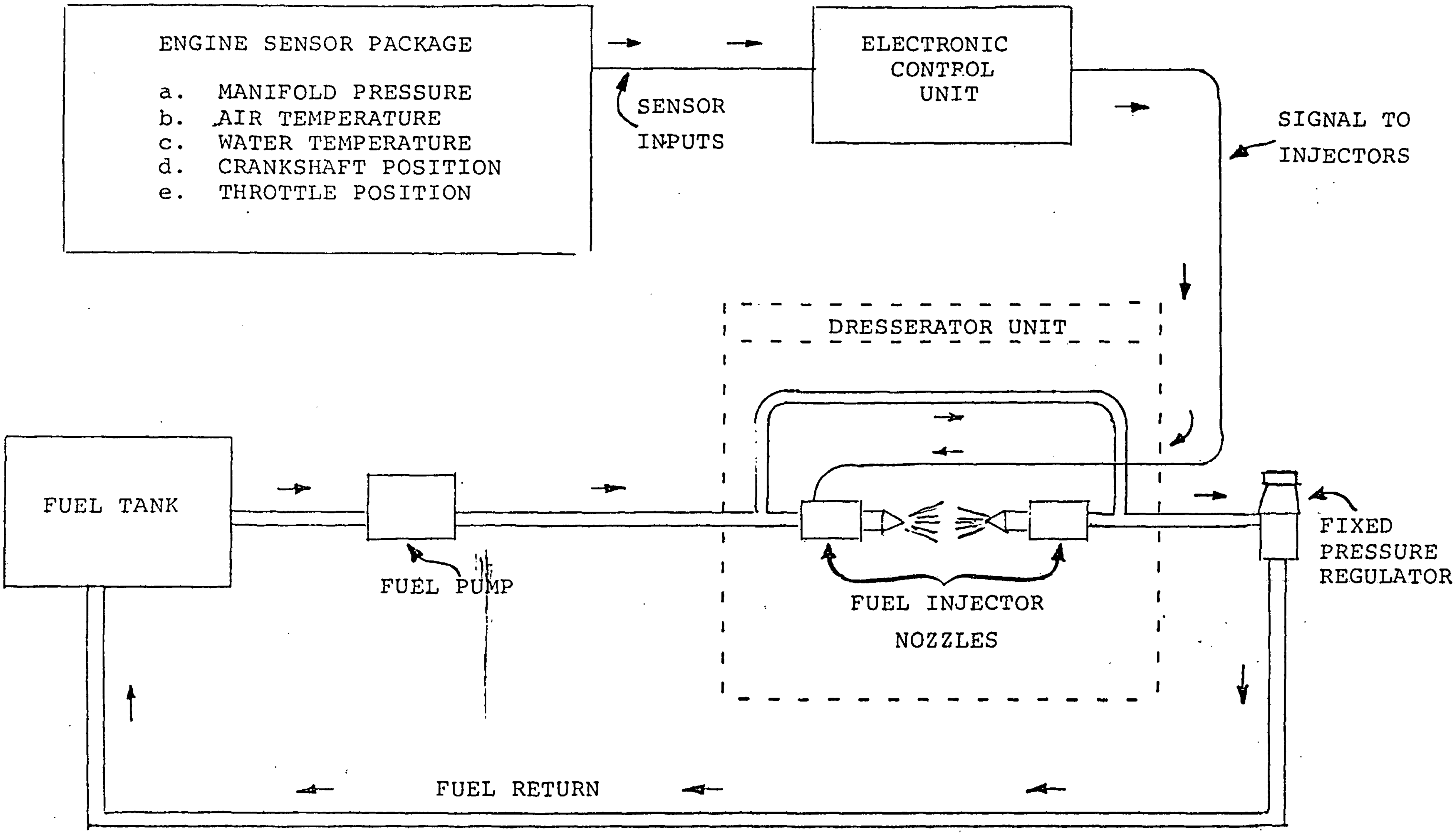


Figure 11

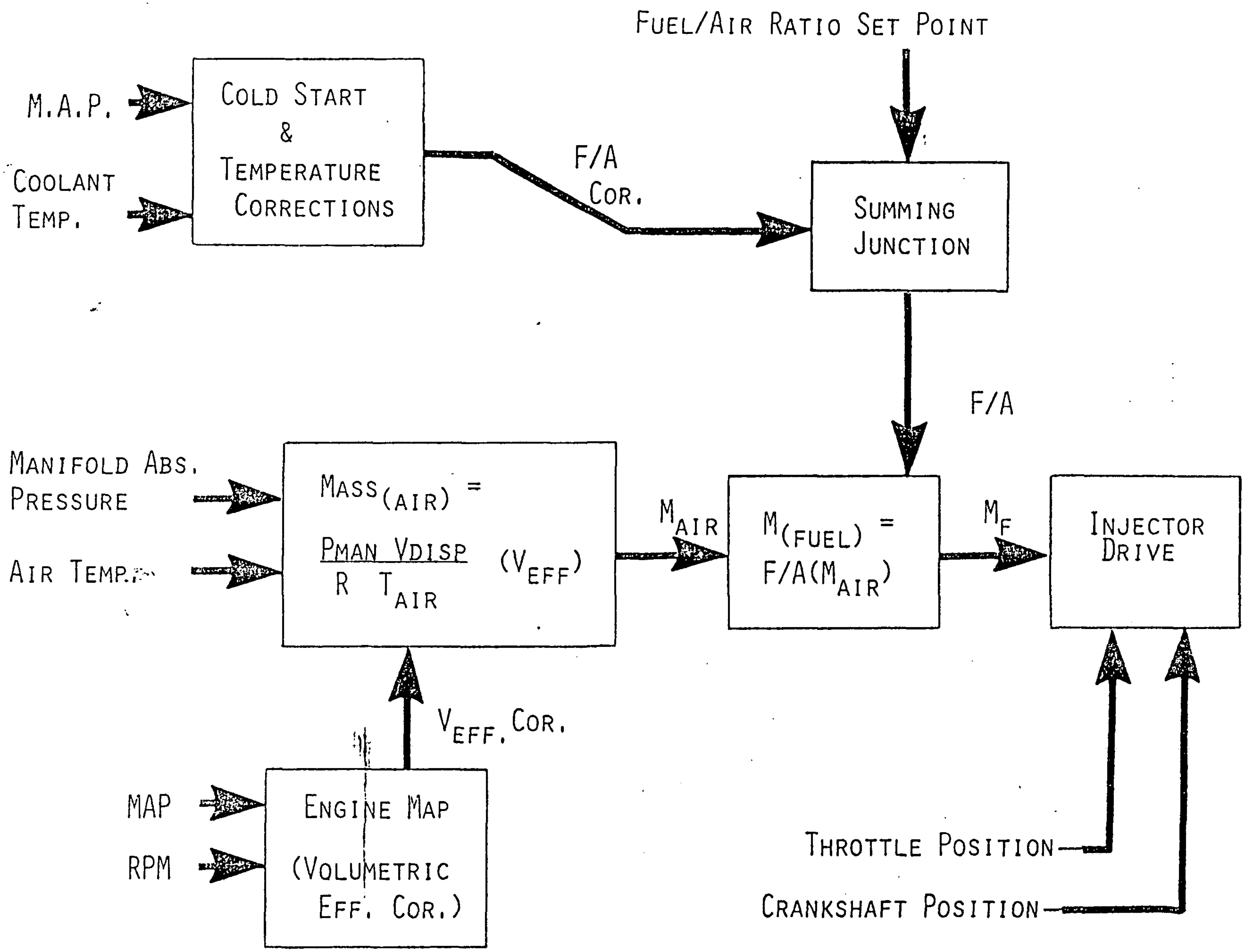

FUEL/AIR RATIO SET POINT
M.A.P.
COOLANT TEMP.
COLD START & TEMPERATURE CORRECTIONS
F/A COR.
SUMMING JUNCTION
F/A
MANIFOLD ABS. PRESSURE
AIR TEMP.
MASS(AIR) = PMAN VDISP / R TAIR (VEFF)
MAIR
M(FUEL) = F/A(MAIR)
MF
INJECTOR DRIVE
VEFF. COR.
MAP
RPM
ENGINE MAP (VOLUMETRIC EFF. COR.)
THROTTLE POSITION
CRANKSHAFT POSITION

Figure 12

an open-loop. A commercial system would use a closed-loop function in a hybrid system which would operate open-loop and only utilize the oxygen sensor closed-loop as a calibrating means. Thus, we avoid the A/F ratio cycling necessary to sense the stoichiometric point during most of the operation. This is a significant factor in our results as it helps to maintain our cycle-by-cycle A/F ratio control which we feel is necessary for high TWC catalyst efficiency.

Results

The inductor and fuel control system have been operated and tested in two modes. The first was lean operation at a 1.5 gpm NOx level. Tests were run at DATeC and at the General Motors facility in Van Nuys. The latter confirm our results with the exception that we tend to measure a slightly higher NOx level and a slightly lower economy. However, when compared to the base car baseline values, we show a consistent economy gain, as did the GM results. These results are shown in Figure 13. Lean operation results are run without an air pump and are run without EGR in the range of 18.5/1 or with EGR in the range of 17.5/1. In the lean operation, we utilized an old-type, vacuum-operated EGR valve since we did not have ported signals for control of the back-pressure EGR. Our economy suffered because of this.

Additional results are shown on Figure 13 utilizing another device that we are developing called an "Economizer". This is a very simple, low-cost device which improves economy in the range of 5-10%. As can be seen with these results, the economy improved an additional 5% over the baseline economy when the Economizer was incorporated into the system.

LEAN OPERATION RESULTS

LAB	HC, GPM	CO, GPM	NO_X, GPM	MPG CITY	MPG HWY
DATEC	0.22	1.67	1.80	12.70	17.90
DATEC	0.28	1.96	1.67	13.00	
GM	0.34	1.01	1.48	13.56	18.10
GM	0.33	0.95	1.47	13.51	18.35
BASELINE (GM)	0.22	2.35	1.22	12.89	17.40
WITH ECONOMIZER					
DATEC	0.33	1.22	1.72	13.30	18.3
GM	0.52	0.81	1.50	14.15	19.54

Figure 13

Stoichiometric operation results are shown in Figure 14, as run at DATeC, GM, and at the California Air Resources Board. All laboratories agree on the emissions. The only variation between labs was on the economy, again ours being lowest. These results show an economy gain in the range of 10% over the base car. Results are also shown without an Economizer, again showing an approximate 0.5 mile per gallon difference. Recently, we found that we could operate with a single three-way catalyst in place of the dual catalyst and eliminate the air pump and oxidation catalyst, achieving even lower NOx levels at the same economy gain. These resul are shown in Figure 14A along with results without the Economizer.

Development Status

The current development status of the Model II Inductor system puts it in position to be readily adapted in minimum time to any size of automobile. There are no fundamental unknowns. The system has been carefully researched and incorporates the latest and most up-to-date findings of the Dresserator principle. The manufacturability has been studied intensively by Ford and the system found to be easily manufacturable at low cost. In summary, the current system is:

- a prototype adaptable to commercial use
- manufacturable
- no critical tolerances
- few moving parts
- low maintenance
- low cost
- adaptable to various engine sizes

A comparison of the Dresserator Model II system with other potential systems at various emission levels is shown in Figure 15. At the I.5 gpm NOx level or for utilization of the sytem in Europe, we would recommend a lean operation with a float-fed Inductor. Under these conditions, one would gain 10-20% in economy and have

STOICHIOMETRIC OPERATION RESULTS
TWC + OXIDATION CATALYSTS

LAB	HC,GPM	CO,GPM	NO_X, GPM	MPG CITY	MPG HWY
DATEC	0.29	2.51	0.34	13.53	18.6
DATEC	0.28	2.83	0.33	13.60	
GM	0.24	1.60	0.42	14.24	--
GM	0.30	2.12	0.33	14.23	19.02
GM	0.29	2.17	0.33	14.11	19.01
GM	0.28	1.93	0.48	14.70	--
ARB *	0.29	2.49	0.297	14.20	18.70
ARB *	0.36	3.42	0.32	14.10	18.70
BASELINE (GM)	0.22	2.35	1.22	12.89	17.40
WITHOUT ECONOMIZER					
DATEC	0.22	2.26	0.37	13.13	--

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* See Appendix A

Figure 14

STOICHIOMETRIC OPERATION RESULTS

SINGLE TWC ONLY

LAB	HC, GPM	CO, GPM	NO_X, GPM	MPG CITY	MPG HWY
DATEC	0.28	2.97	0.09	13.63	—
DATEC	0.36	3.12	0.11	13.58	—
WITHOUT ECONOMIZER					
DATEC	0.20	2.73	0.36	12.60	—
	0.20	3.10	0.29	12.75	—
GM	0.26	2.97	0.28	13.11	—

Figure 14A

SYSTEM COMPARISONS

SYSTEM	OX. CATALYST	EGR + TWC	EGR + TWC
CRITICAL STANDARD	0.41 HC 1.5 NOx	0.41 HC 1.0 NOx	0.41 HC 0.4 NOx
OPERATION	LEAN	STOICHIOMETRIC	STOICHIOMETRIC
DRESSERATOR INDUCTOR FUEL CONTROL	FLOAT FED	PRESSURE + ELECTRONICS	PRESSURE + ELECTRONICS
ECONOMY GAIN	10 - 20%	5 - 15%	5 - 15%
COST ADVANTAGE	$80	$80 - $100	$80 - $100
COMPETITION	AIR, EGR, OX. CATALYST	F.B. CARB. OR EFM, EGR, TWC, AIR, OX. CAT.	FI, FB CARB. OR EFM, EGR, TWC, AIR, OX. CAT.

Figure 15

an $80 advantage over other systems, mainly because we do not need an air pump or EGR. At the 1 gpm NOx level, we would operate at stoichiometric A/F ratio with a three-way catalyst and EGR using a pressure fed metering system. We anticipated and have demonstrated an economy gain of 5-15% and would have a considerable cost advantage, in the range of $80-$100, over a feedback carburetor or EFM fuel control system, including EGR three-way catalyst, air and oxidation catalyst. With our most recent results, the comparison at 0.4 gpm NOx becomes essentially the same as thatat the 1 gpm level. In addition, it appears that we have the potential of meeting the 1 gpm NOx standard without using EGR.

The Model II Inductor system, as described above, does not fully utilize all of the potential of the Dresser sonic carburetor concept. As mentioned earlier, the sonic carburetor is a mass flow metering and measuring device. Thus, the Inductor itself can be used to measure air flow to the engine rather than computing it from speed and density. A schematic showing an advance control system utilizing fully the Dresser concept is shown in Figure 16. Air flow is measured by a throttle position sensor. Flow would be corrected for air temperature and atmospheric pressure variation. The atmospheric pressure correction would be by absolute manifold pressure on start. Once in operation, the pressure correction is taken care of by the oxygen sensor utilized in ~~the semi-open~~ loop system, EGR would be programmed using the sonic principle in a sonic EGR valve. However, it is totally independent of the air fuel system since we have a primary measure on the air mass flow through the throttle body itself. This scheme provides the ultimate in simplicity for a control system with a minimum of variations which can detract from the ability of the system to control and is unique to the Dresserator concept. An additional benefit is the elimination of the need for extensive engine mapping to determine volumetric efficiency.

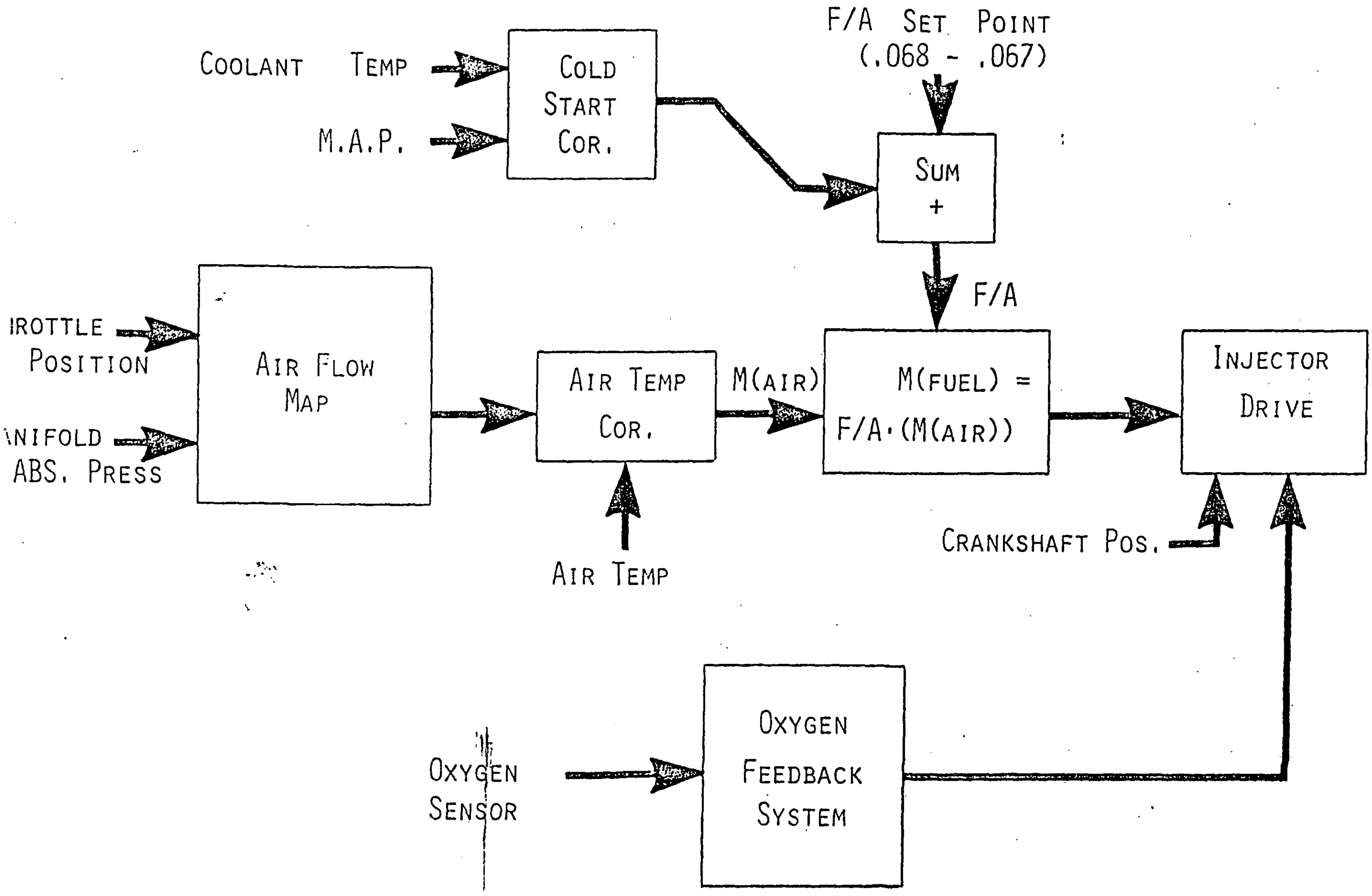
COOLANT TEMP
M.A.P.
COLD START COR.
F/A SET POINT (.068 - .067)
SUM +
F/A
IROTTLE POSITION
ANIFOLD ABS. PRESS
AIR FLOW MAP
AIR TEMP COR.
AIR TEMP
M(AIR)
M(FUEL) = F/A·(M(AIR))
INJECTOR DRIVE
CRANKSHAFT POS.
OXYGEN SENSOR
OXYGEN FEEDBACK SYSTEM

Figure 16