75-27 GRS

Evaluation of a M-151 Jeep and Two 1973 Ford Capris Powered By 141 CID PROCO Stratified Charge Engines

June 1975

Technology Assessment and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Environmental Protection Agency

Background

The Environmental Protection Agency receives information about many systems which appear to offer potential for emission reduction or fuel economy improvement compared to conventional engines and vehicles. EPA's Emission Control Technology Division is interested in evaluating all such systems, because of the obvious benefits to the Nation from the identification of systems that can reduce emissions, improve economy, or both. EPA invites developers of such systems to provide complete technical data on the system's principle of operation, together with available test data on the system. In those cases for which review by EPA technical staff suggests that the data available show promise, attempts are made to schedule tests at the EPA Emissions Laboratory at Ann Arbor, Michigan. The results of all such test projects are set forth in a series of Technology Assessment and Evaluation Reports, of which this report is one.

The conclusions drawn from the EPA evaluation tests are necessarily of limited applicability. A complete evaluation of the effectiveness of an emission control system in achieving performance improvements on the many different types of vehicles that are in actual use requires a much larger sample of test vehicles than is economically feasible in the evaluation test projects conducted by EPA. For promising systems it is necessary that more extensive test programs be carried out.

The conclusions from the EPA evaluation test can be considered to be quantitatively valid only for the specific test car used; however, it is reasonable to extrapolate the results from the EPA test to other types of vehicles in a directional or qualitative manner i.e., to suggest that similar results are likely to be achieved on other types of vehicles.

The Programmed Combustion Process (PROCO) or "stratified charge" engine concept has been under development at the Ford Motor Company since 1958. Conversion of an engine to the PROCO stratified charge operation requires a cylinder head which incorporates direct cylinder fuel injection, spark plugs and high swirl intake ports. Pistons are changed to 11:1 compression ratio units with "cups" in their centers forming the combustion chambers.

The principle advantages of the PROCO are that (1) it is capable of operating at leaner overall A/F ratios and therefore with less throttling than conventional carbureted, spark ignited internal combustion engines, (2) it has low NOx formation due to the rich/lean, stratified charge combustion, (3) it can use high compression ratios with lower octane fuel than required with conventional gasoline engines because there is no combustible mixture in the "end gas".

Under contracts with the United States Army Tank-Automotive Command initiated in December of 1967, Ford Converted ten L-141 military utility truck engines to the Programmed Combustion Process. Four of these engines were installed in M-151 jeeps which were tested for emissions and durability. Another four engines were used in dynamometer testing. At the conclusion of the Army program, the Environmental Protection Agency contracted to have three of the latter four engines installed in 1973 Ford Capris. The purpose was to evaluate the PROCO engine in a vehicle more representative of typical passenger cars than the military jeep.

This report covers the testing of number three of the four military jeeps, and preliminary testing of two of the Capris. Results of previous tests on jeeps one and two can be found in Test and Evaluation Branch report "C" dated May 1970 and report 71-23 dated April 1971. Also included in this report are results of non-regulated emission tests conducted on one of the PROCO Capris and a standard 2.0 litre Capri at Southwest Research Institute. Photographs of the white PROCO Capri and its engine compartment are shown in Figures 1 and 2.

Engine Description

The engines used were L-141 military engines converted to the Programmed Combustion Process. Their specifications are given in Table I. Figure 3 is a cross section of the cylinder head and piston configuration. A summary of the components involved in this conversion and the effect are as follows.

Spark timing and fuel injection are controlled by a special injection pump ignition distributor unit designed by Ford. This unit includes an aneroid barometer which senses absolute manifold pressure and adjusts fuel delivery accordingly. Fuel-air ratio controlis therefore maintained despite altitude changes or day to day change in barometric pressure.

Fuel injectors are low opening pressure (300 psi), low penetration units which create a stratified "cloud" of fuel-air mixture in the cylinder. Burning is initiated near the richest portion of the fuel cloud. The initial rich phase of the combustion has a significant effect on NOx emissions since the initial portion of the charge is subject to high temperature for the longest period of time. Low oxygen concentration in this rich zone results in lower NOx levels than those produced by premixed charge (conventional spark ignition) engines of the same overall air-fuel ratio. Stratified charge combustion also reduces the unburned hydrocarbons caused by wall quenching since very little fuel reaches the surfaces of the combustion chamber. The mixture is throttled on the engines evaluated in this program to 24:1 air-fuel at idle, 15:1 at light loads and 17.5:1 at heavier loads.

Figure 1. Stratified Charge (PROCO) Powered Capri

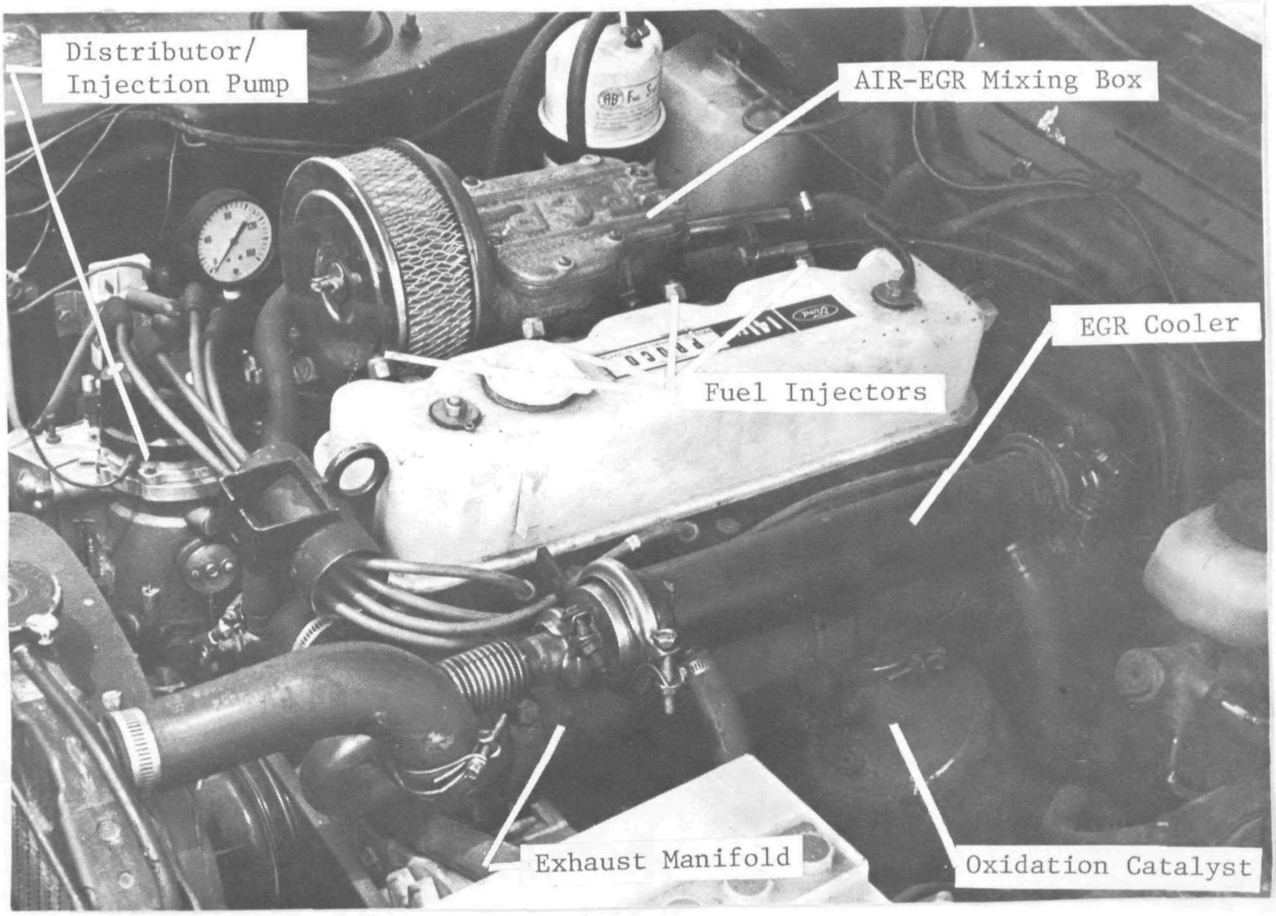

Figure 2. Engine Compartment of PROCO Capri

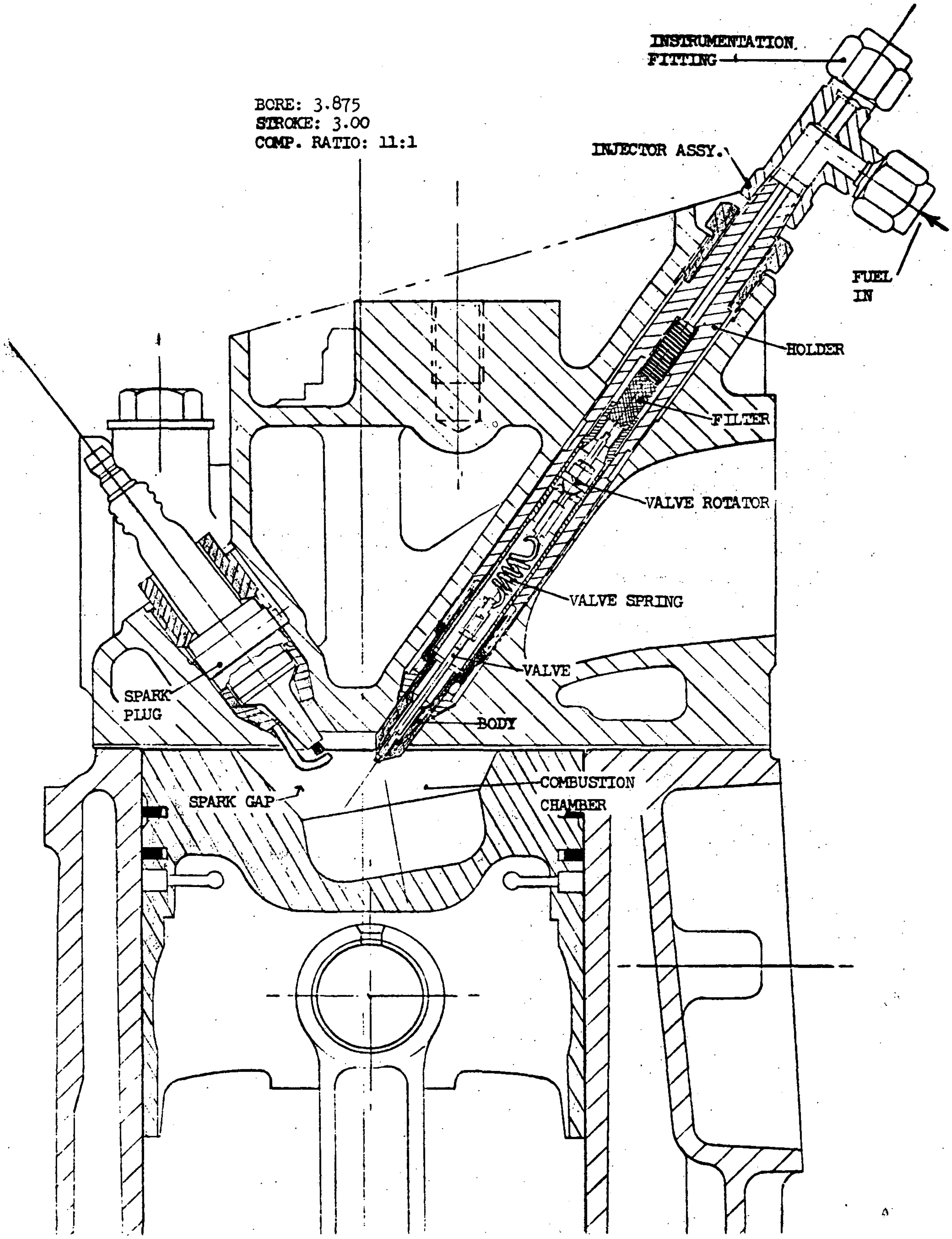

Figure 3. Cross Section of 141 CID PROCO Engine Head and Piston Assembly

Table 1

Engine Description

type	4 stroke, stratified charge Otto Cycle, OHV, in-line 4 cylinder
bore x stroke	3.875 x 3.00 in./98.4 x 76.2 mm
displacement	141.5 cu. in./2320 cc
compression ratio	11:1
maximum power @ rpm	approx. 71 hp/53 kw @ 4000 rpm
fuel metering	low pressure (300 psi) cylinder injection
fuel requirement	no lead, RON requirement not determined (91-96 RON used during test program)

Emission Control System

basic type	stratified charge, exhaust gas recirculation, low thermal inertia exhaust manifold, noble metal monolith catalyst, positive crankcase ventilation

The engines were equipped with noble metal monolith oxidation catalysts close coupled to the exhaust manifolds. All tests covered in this report are for catalysts with less than 2,000 accumulated miles. High rates of exhaust gas recirculation (EGR) are also employed to lower NOx formation. Exhaust is collected before the catalyst, cooled, and then drawn into the engine through the EGR valve at the throttle plate. The average EGR rate for the jeep is approximately 15% and 8% for the Capris. For some tests on the jeep, exhaust was recirculated during all operating conditions including idle. For other tests on the jeep and all tests on the Capris, modifications were made to eliminate EGR and enrich the mixture to 13:1 A/F when the engine was operated at wide open throttle (W.O.T.).

Test Procedures

To obtain a comprehensive evaluation of the PROCO stratified charge engine as a light duty power plant, nine different test types were performed:

1. 1975 Federal Test Procedure (FTP) for HC, CO, NOx emissions and urban cycle fuel economy from light duty vehicles.

2. Highway Cycle tests for emissions and fuel economy during non-urban driving.

3. Heavy Duty gaseous test procedure (13-mode) for mapping HC, CO, NOx emissions and specific fuel consumption.

4. Light Duty Smoke test

5. Odor tests

6. Oxygenates testing (during 1975 FTP vehicle operation)

7. Noise tests

8. Particulate emission tests

9. Sulfate emission test

For purposes of comparison some of these tests were also conducted on a standard Capri and a prototype Ford LTD. Table 2 identifies which tests each of the vehicles has been subject to up to the present time. Appendix I contains the vehicle descriptions of the PROCO jeep, PROCO Capri, standard Capri, and Ford LTD. The fuel used for all tests was no lead gasoline (.03-.04 gm/gallon lead) with a 91-96 RON.

Table 2 - Tests Performed

	'75 FTP	Highway Cycle	13 Mode	LD Smoke	Odor	Oxygenates	Noise	Particulates	Sulfates
Proco Jeep #3	x								
Proco Capri (Blue)	x		x	x	x	x	x	x	
Proco Capri (White)	x	x							x
Standard Capri					x		x		
Ford LTD					x				
Testing Location									
Test Performed by	EPA/TAEB	EPA/TAEB	SwRI	SwRI	SwRI	SwRI	SwRI	EPA/ORD & Dow Chemical	EPA/CAB

EPA/ORD - EPA Office of Research and Development, Research Triangle Park, North Carolina
EPA/TAEB - EPA, Emission Control Technology Division, Technology Assessment and Evaluation Branch, Ann Arbor, MI
EPA/CAB - EPA, Emission Control Technology Division, Characterization and Application Branch, Ann Arbor, MI
SwRI - Southwest Research Institute, San Antonio, Texas

The specific test procedures and analytical systems used for each emission category are described in Appendix II. Whenever possible, recognized procedures published in the Federal regulations were employed. Where Federal procedures, or chassis versions of Federal procedures did not exist, existing procedures for Heavy Duty vehicles were modified or adapted as necessary for purposes of this evaluation.

Test Results

1. 1975 FTP Emissions

Results of 75 FTP tests are summarized in Table 3. Detailed results are presented in Appendix III. The jeep displayed the lowest emissions, with all gaseous emissions below even the 1978 Federal Statutory Standard. With full EGR, the NOx value of .26 grams per mile was well within the 0.4 grams per mile 1978 Standard.

The use of full time EGR caused some loss in performance. Figures 4, 5, and 6 are the drivers traces of the 75 FTP in the region of 180 to 300 seconds into the hot transient cycle. The hatched area represents the difference between the prescribed speed time trace and the actual trace generated by the vehicle. A large difference represents the inability of the vehicle to maintain an acceleration rate typical of present production cars. It is clear in Figure 4 that the PROCO jeep with full EGR was unable by a wide margin, to keep up with the trace. With EGR cutoff and fuel enrichment, at WOT the jeep was able to follow the trace much more closely (See Figure 5). The modification increased the NOx emissions from .26 to .39 grams per mile. It should be noted that some of the jeeps difficulty in following the urban cycle was due to its drive train. Designed for military use, the transmission had gear ratio's atypical of passenger cars. First gear was very low (5.7:1) and was not used, the vehicle being started in second gear for the test. The front wheel drive was disengaged during testing but drive train frictional losses were still higher than for conventional passenger cars according to sources at Ford and USATACOM.

The PROCO Capris, with the Capri 4 speed transmission, and EGR cut-off and fuel enrichment at WOT were more capable of following the trace (See Figure 6). Zero to sixty mph acceleration times of the PROCO Capri measured on the chassis dynamometer averaged 18.0 seconds with a 2750 lb. inertia weight. The 0 to 60 time for the standard 1973 2.0 litre Capri was 13.0 seconds.

Table 3
1975 Federal Test Procedure Emission Results for PROCO Vehicles. Emission Results in Grams/Mile (Grams/Kilometre) Fuel Economy in Miles/Gallon (Litre/100 Kilometres)

Vehicle Test Number	IW	HC	CO	CO_2	NOx	City Cycle Fuel Economy
Jeep #3						
12-2123	2750	0.23 (0.14)	0.50 (0.31)	416 (259)	0.27 (0.16)	21.3 (11.1)
18-120	2750	0.25 (0.15)	0.20 (0.12)	444 (276)	0.26 (0.16)	19.9 (11.8)
18-124	2750	0.26 (0.16)	0.28 (0.17)	440 (274)	0.37 (0.22)	20.2 (11.7)
18-125	2750	0.21 (0.13)	0.16 (0.09)	443 (275)	0.39 (0.24)	20.0 (11.8)
18-127	2250	0.23 (0.14)	0.29 (0.18)	450 (280)	0.30 (0.18)	19.6 (12.0)
Blue Capri						
16-1131	2750	0.16 (0.10)	0.84 (0.52)	380 (236)	1.45 (0.90)	23.2 (10.1)
15-58	2750	0.15 (0.90)	0.32 (0.19)	376 (234)	1.55 (0.96)	23.5 (10.0)
White Capri						
15-4089	2500	0.16 (0.90)	0.73 (0.45)	380 (236)	0.65 (0.40)	23.2 (10.1)
15-4055	2500	0.17 (0.10)	0.82 (0.50)	391 (243)	0.81 (0.50)	22.6 (10.4)
15-4043	2750	0.16 (0.10)	0.74 (0.45)	392 (244)	0.81 (0.50)	22.5 (10.4)
15-156	2750	0.23 (0.14)	0.87 (0.54)	388 (241)	0.79 (0.49)	22.7 (10.4)
15-17	2750	0.15 (0.09)	0.50 (0.31)	367 (228)	0.88 (0.54)	24.1 (9.76)
1975 Federal Interim Standard		1.5 (0.93)	15.0 (9.3)		3.1 (1.93)	
1977 Federal Interim Standard		1.5 (0.93)	15.0 (9.3)		2.0 (1.2)	
1978 Federal Statutory Standard		0.41 (0.25)	3.4 (2.1)		0.4 (0.25)	

After the PROCO engines were installed in the Capris there was difficulty in getting them to function properly. Misfire was a frequent problem. The engines performed satisfactorily on the tests reported here but it is not certain that they were in optimum tune for performance or emissions. The two Capris had similar hydrocarbon and carbon monoxide emissions of around .17 grams/mile and .7 grams/mile respectively. These are well within the 1978 Statutory levels of .41 HC and 3.4 CO in grams per mile. However some degradation would be anticipated as more mileage is accumulated on the catalysts. The white Capri was calibrated for NOx emissions of .8 grams/mile while the blue Capri averaged 1.5 grams/mile NOx. These values exceeded the 1978 Statutory NOx level of 0.4 but were still within the 1977 NOx Standard of 2.0 grams/mile. As shown in Table 3, the fuel economy of the PROCO vehicles is rather insensitive to NOx calibration level.

The inertia weight of the Capris was close to the break between the 2500 and 2750 pound inertia weight classes so the white Capri was tested in both classes. There was no decernable difference in emissions resulting from the different inertia weight setting.

2. <u>1975 FTP and Highway Cycle Fuel Economies</u>

The fuel economy results of the FTP and highway cycles are summarized in Table 4. Detailed results including Highway Cycle emissions are in Appendices III and IV. For the FTP the jeep had a fuel economy of 20.2 miles/gallon, while the white and blue Capri's averaged 23.2 and 23.3 mpg respectively. The jeep, tested at 2250 instead of 2750 pounds inertia weight, did not get any better mileage. This phenomenon is not unexpected for a vehicle with such a low power to weight ratio since with the lower inertia weight nearly the same power levels are used to drive the more difficult accelerations of the cycle. Instead of the better fuel economy normally associated with lower test weight the jeep achieved the same economy but kept up with the speed-time trace better. Also the jeep with full EGR yielded the same fuel economy.

Table 4

Average '75 FTP and Highway Cycle
Fuel Economies/Fuel Consumption
miles per gallon
(litres per 100 kilometres)

Vehicle	No. of Tests	'75 FTP	No. of Tests	Highway
Proco Jeep #3	4	20.2 (11.7)	-	-
Blue PROCO Capri	2	23.3 (10.1)	-	-
White PROCO Capri	5	23.2 (10.1)	3	32.0 (7.34)

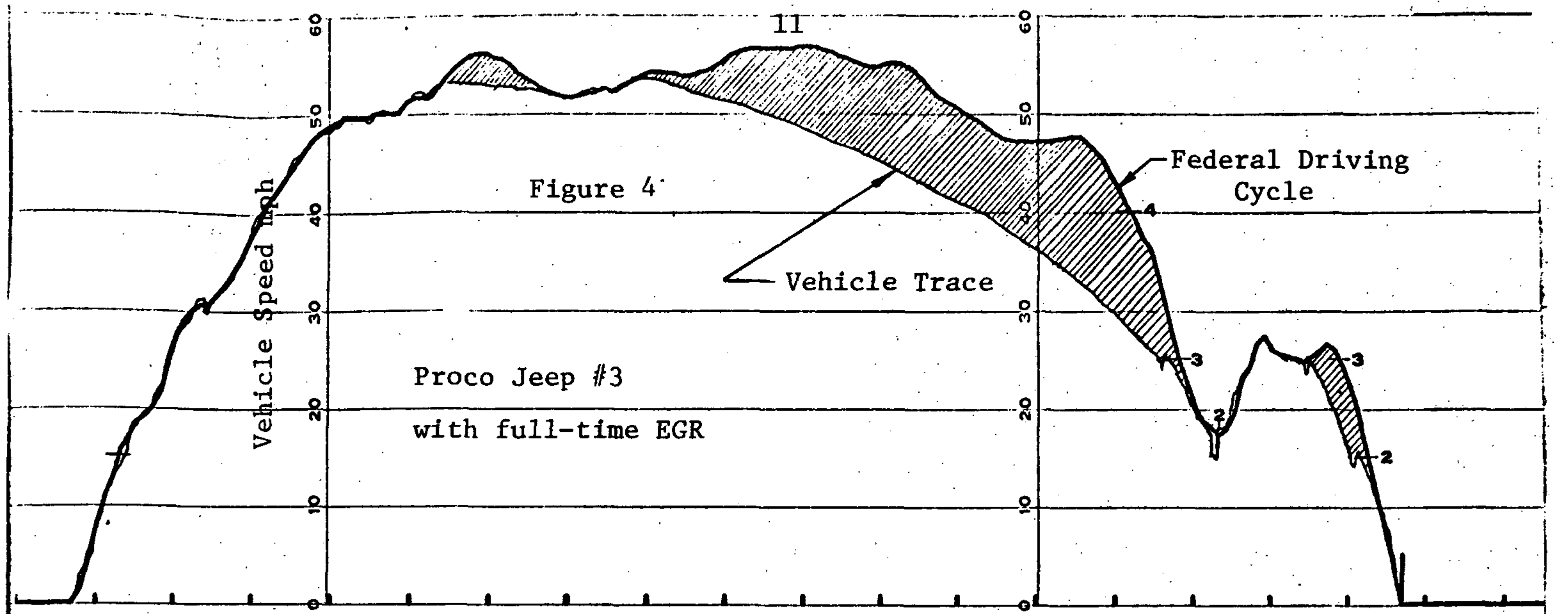
Figure 4
Vehicle Speed mph
Federal Driving Cycle
Vehicle Trace
Proco Jeep #3
with full-time EGR

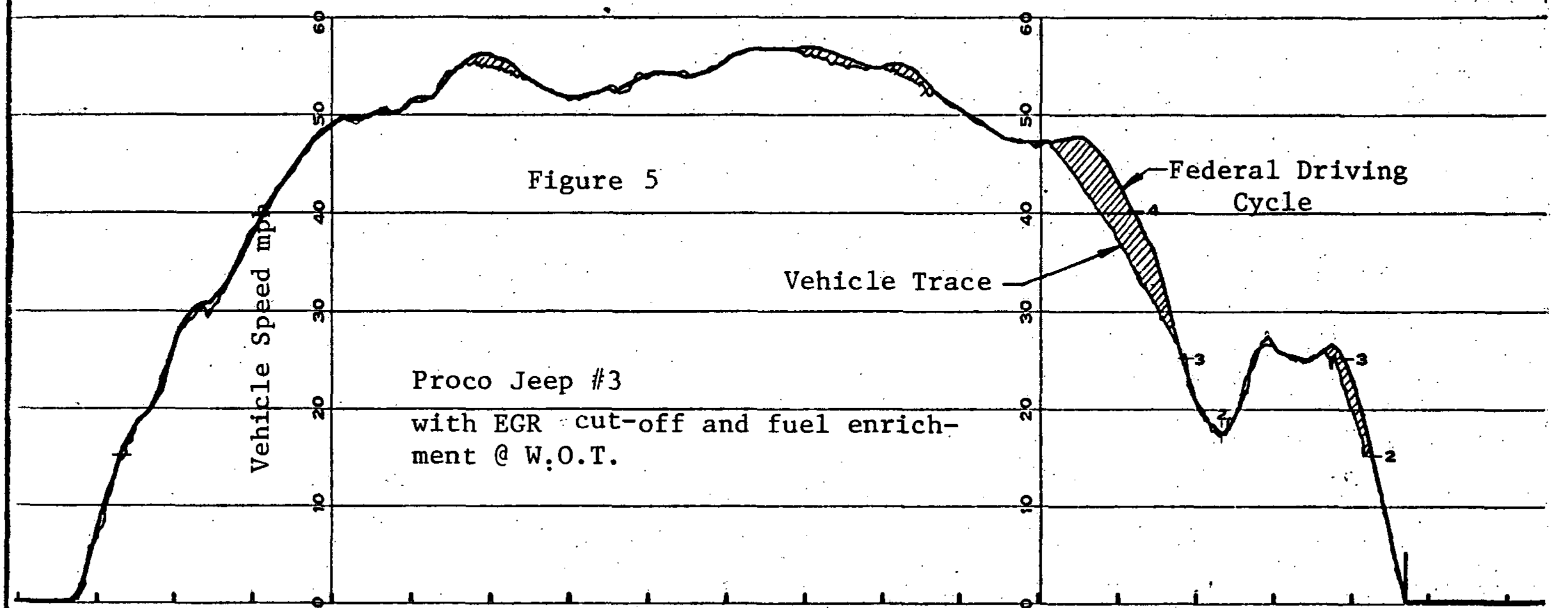
Figure 5
Vehicle Speed mph
Federal Driving Cycle
Vehicle Trace
Proco Jeep #3
with EGR cut-off and fuel enrichment @ W.O.T.

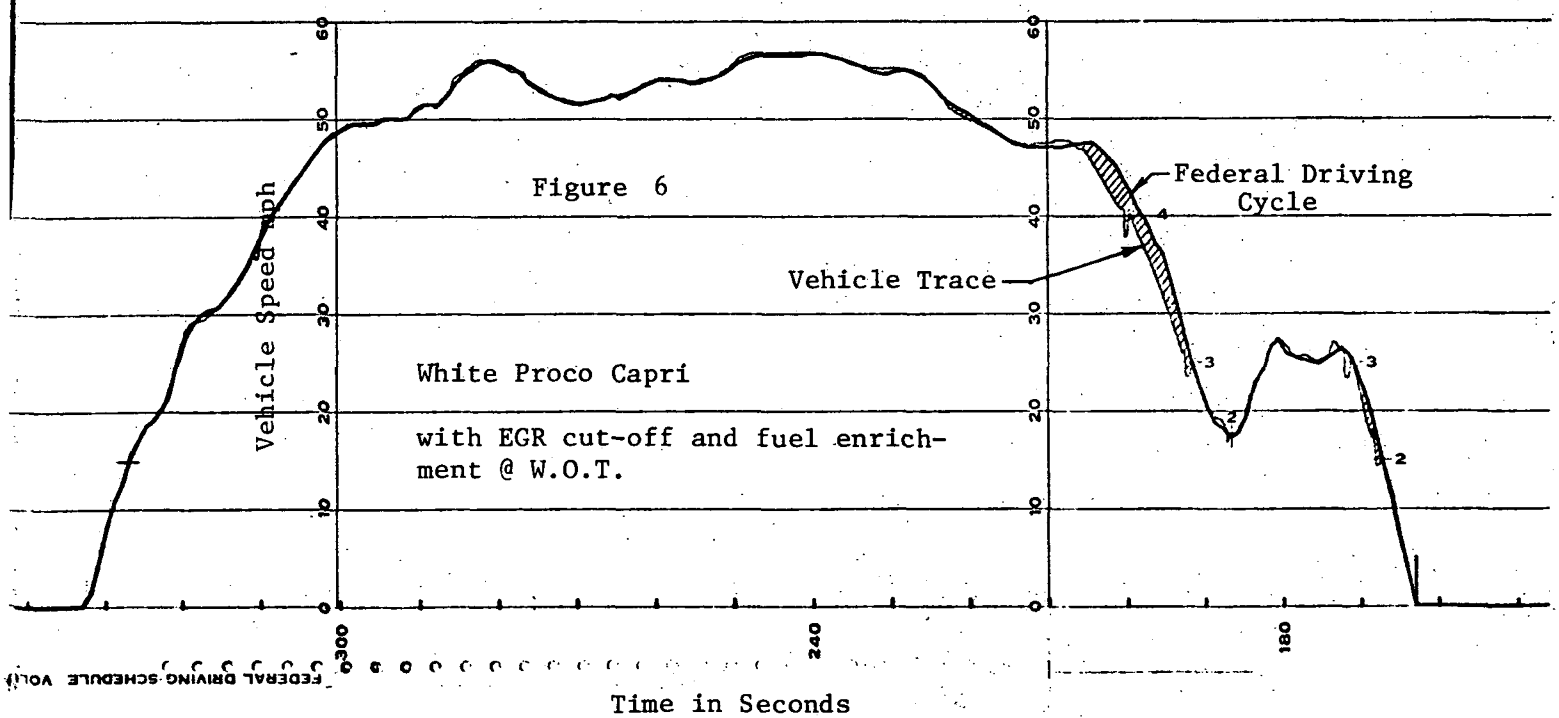
Figure 6
Vehicle Speed mph
Federal Driving Cycle
Vehicle Trace
White Proco Capri
with EGR cut-off and fuel enrichment @ W.O.T.
300
240
180
Time in Seconds

Figure 7 compares the PROCO test results to the 1975 Federal certification FTP fuel economies. The three curves on this Figure represent the maximum, minimum, and sales weighted average fuel economies versus inertia weight of the 75 model year light duty vehicles certified for sale in the 49 states and California. The two Capri's fuel economies fell above the fuel economy range of the 1975 cars, while the jeep's equalled the average. Figure 8 is a similar comparison for the Highway Cycle fuel economies. Only the white Capri was tested on this cycle. Its fuel economy of 31.8 mpg was within the band but above the average of 28.5 mpg for the 2750 pound inertia weight class.

3. Heavy Duty Vehicle Gaseous Emissions

Table 5 displays the results of the HD tests. This chassis version of the test was conducted primarily to see how light duty engine emissions compared to those of heavy duty engine. The PROCO Capri and two other stratified charge engine vehicles were tested for comparison. Unfortunately no normally carbureted engines were tested. The 1977 Federal HD emission standards are 40 gm/bhp-hr for CO (53.6 gm/kw-hr.) and 16 gm/bhp-hr (21.4 gm/kw-hr) for HC and NOx combined.

The Capri's average CO value of 75.6 gm/kw-hr exceeded the standard. A possible reason the PROCO did so poorly on the HC cycle and so well on the LD cycle is the provision made for EGR shut off and fuel enrichment at WOT. This condition was encountered a large percentage of the time in the HD cycle. During the 75 and 100 percent of maximum power modes, large quantities of CO and HC were produced. Due to oxygen insufficiency during these modes, the close coupled noble metal catalyst was unable to control these emissions. Were the PROCO engine to be set up for low emissions during heavy duty operation, fuel enrichment could be eliminated or an air pump could be installed. The NOx emissions of 5.73 gm/kw-hr were lower than the other two stratified charge engines and were comparable to those of the diesels tested.

4. Smoke

Using the EPA light extinction meter method of measurement the exhaust was monitored continuously for smoke throughout the 1975 LD-FTP. The results of this test are summarized as peak and average opacity values in Table 6. The limit of visible smoke for this method is 3 to 4 percent opacity. The PROCO Capri exhaust was consistently between 0 and 1 percent opacity except during engine starting and hard accelerations, where the maximum reading of 2 percent was recorded. The overall average of 0.5% is clearly acceptable and is comparable to normally carbureted gasoline engines.

Figure 7

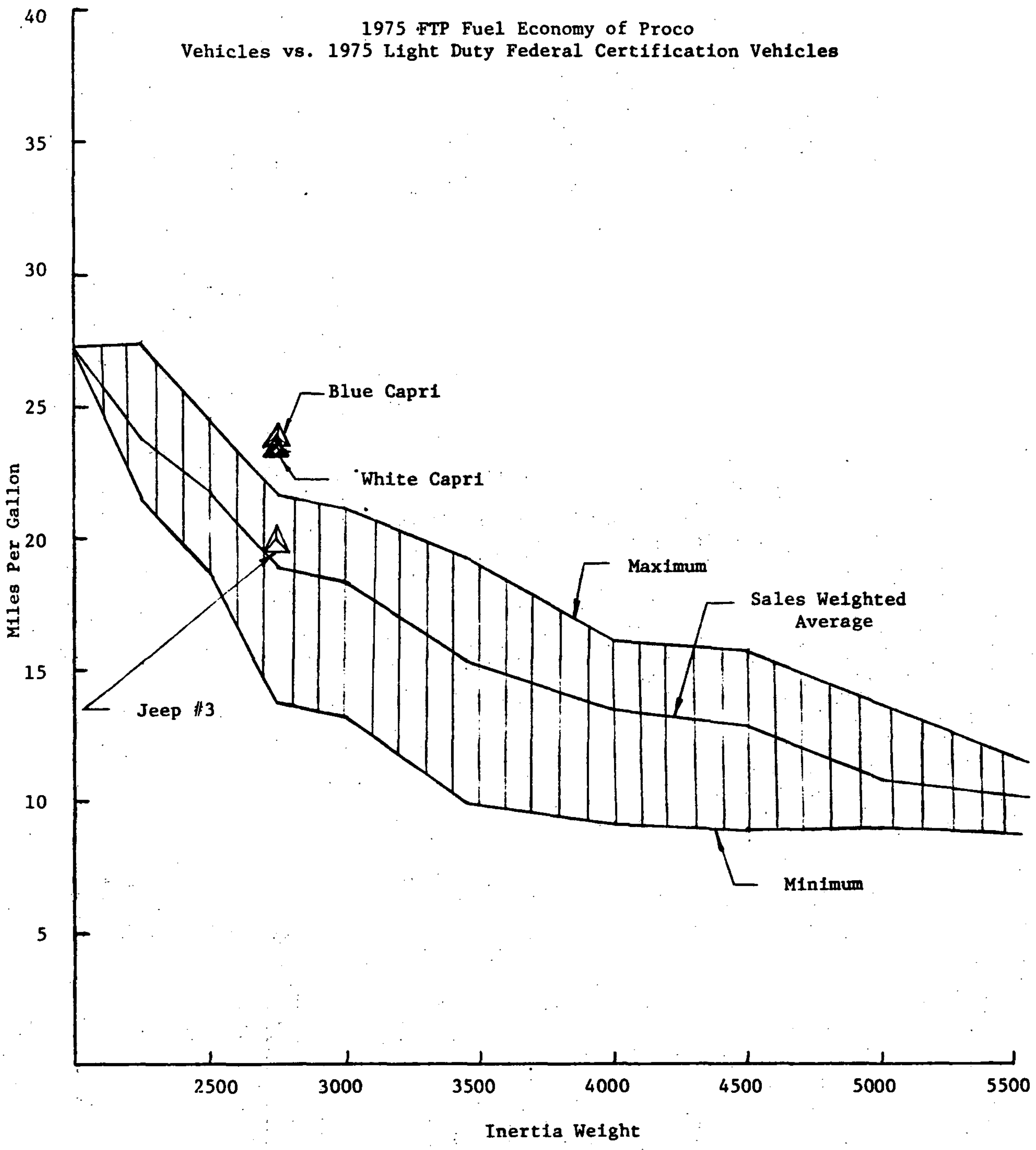
1975 FTP Fuel Economy of Proco
Vehicles vs. 1975 Light Duty Federal Certification Vehicles
40
35
30
25
20
15
10
5
Miles Per Gallon
Blue Capri
White Capri
Jeep #3
Maximum
Sales Weighted
Average
Minimum
2500
3000
3500
4000
4500
5000
5500
Inertia Weight

Figure 8

Highway Cycle Fuel Economy of Proco
Capri vs. 1975 Light Duty Federal Certification Vehicles

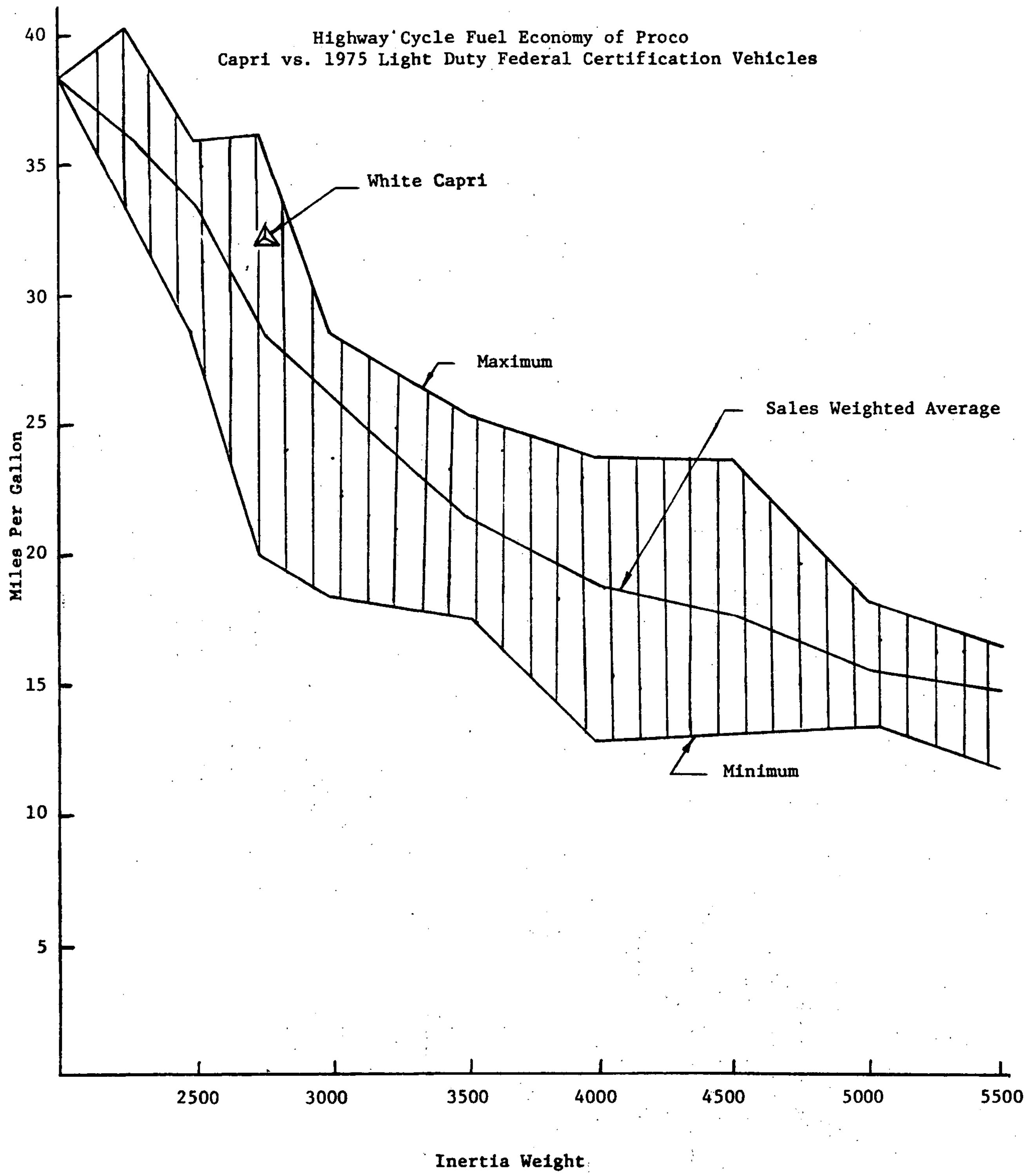

Table 5

Average 13-Mode Emissions
(Chassis Alternative of HD Engine Test)

Vehicle		gm/bhp-hr	gm/kw-hr
Blue PROCO Capri	HC	2.810	3.769
	CO	56.38	75.62
	NOx	4.27	5.73
	HC + NOx	7.08	9.50
HDV Emission Standards			
1974 Statutory	CO	40	54
	HC + NOx	16	21
Fuel Consumption		lb/bhp-hr	gm/kw-hr
		0.563	342

Table 6

Smoke Opacity Values from the Smoke Traces
During the LA-4 1975 LDV FTP

	Ford PROCO Capri
Cold Start (Peak %)	1.3
Cold Idle (Avg. %)	0.4
Accel (Peak %)	0.8
Idle (125 sec. Avg. %)	0.1
Accel to 56 MPH (Peak %)	2.0
Hot Start (Peak %)	1.6
Hot Idle (Avg. %)	0.4
Accel (Peak %)	0.6
Idle (Avg. %)	0.3
Accel to 56 MPH (Peak %)	1.0
Avg. % (1st 505 sec.)	0.8
Avg. % (Balance 23 min.)	0.5
Avg. % (505 sec. Hot Start)	0.4
Estimated Avg. % Overall	0.5

5. Odor

5a. Odor Panel

Ten mode odor test sequences were conducted on the PROCO and standard Capris and a catalyst equipped Ford Ltd. The LTD was included as an example of a conventional gasoline engine with a catalyst emission control package. The exhaust gases of the vehicles were diluted and analyzed by a trained odor panel of ten people. They rated, on intensity scales of 1 to 4, four sub-odor qualities. These were burnt-smoky "B", oily "O", aromatic "A", and pungent "P". In addition an overall "D" odor rating was made on a scale of 1 to 12. Table 7 contains the results of the odor panel for the steady state conditions. Figure 9 is a bar graph comparison of the combined odor ratings of the three vehicles for each mode. The PROCO Capri consistently had the lowest odor rating except for the Cold Start and accel modes.

5b. Diesel Odor Analytical System (DOAS)

During the steady state modes of the ten mode odor test sequence extensive chemical analyses were made. These included measurement of HC, CO, NO, NOx, CO_2, O_2, acrolein, formaldehyde, aliphatic aldehydes, liquid chromatographic oxygenates (LCO) and liquid chromatographic aromatics (LCA). LCO and LCA comprise the results of DOAS. TIA (total intensity of aroma), which equals $1 + \log_{10}$ LCO, has been found to correlate with results of the odor panel. Table 8 gives the results of these analyses for the three vehicles. By this analysis, the PROCO was again the lowest producer of odor of the three cars. During the intermediate and high speed high load conditions of the odor test, the PROCO Capri did not produce the large quantities of HC and CO produced in the high load modes of the HD tests. The probable reason is that the high load conditions of the odor test did not require W.O.T. operation as they were less severe. Even so at the high speed high load conditions the exhaust oxygen content was down to 0.4% compared to 1.2 to 8.3% for all other steady state conditions.

6. Oxygenates

A variety of oxygen containing hydrocarbons were collected during 75-FTP tests on the PROCO Capri. By wet chemical methods, aliphatic aldehydes (aldehydes), formaldehyde and acrolein were determined in grams/mile. Table 9 displays the results of these analyses. The values are very low as might be expected from a vehicle with low HC emissions. Generally oxygenates and unburned hydrocarbons go together, the more HC the more aldehydes, formaldehyde and acrolein. Results from several diesel vehicles were approximately an order of magnitude greater.

Table 7

Average Odor Panel Ratings at 100:1 Dilution

Vehicle Condition	Odor Kit	Ford LTD	Capri Std.	Capri PROCO
		Steady State Results		
Intermediate Speed, no load	D	2.0	2.7	0.8
	B	0.8	0.8	0.4
	O	0.4	0.8	0.1
	A	0.6	0.5	0.2
	P	0.2	0.6	0
Intermediate Speed, mid load	D	1.5	3.0	0.8
	B	0.6	0.9	0.4
	O	0.3	0.8	0.1
	A	0.6	0.6	0.3
	P	0.2	0.7	0.1
Intermediate Speed, high load	D	1.2	3.4	1.0
	B	0.5	0.9	0.4
	O	0.4	0.9	0.2
	A	0.4	0.7	0.3
	P	0.1	0.8	0.1
High Speed No load	D	1.5	2.2	0.8
	B	0.7	0.8	0.4
	O	0.4	0.6	0.2
	A	0.5	0.5	0.2
	P	0	0.4	0
High Speed Mid load	D	1.1	3.5	1.1
	B	0.5	1.0	0.5
	O	0.3	0.9	0.3
	A	0.4	0.6	0.2
	P	0	0.8	0.1
High Speed High load	D	1.4	3.3	1.3
	B	0.7	0.9	0.5
	O	0.5	0.8	0.3
	A	0.4	0.7	0.4
	P	0.1	0.8	0.1
Idle Speed No load	D	1.2	3.3	0.7
	B	0.6	0.9	0.3
	O	0.4	0.8	0.1
	A	0.3	0.7	0.3
	P	0.1	0.8	0.1

Figure 9

Comparison of Average Odor Ratings
for Proco Capri, Standard Capri and Ford LTD
w/Catalyst

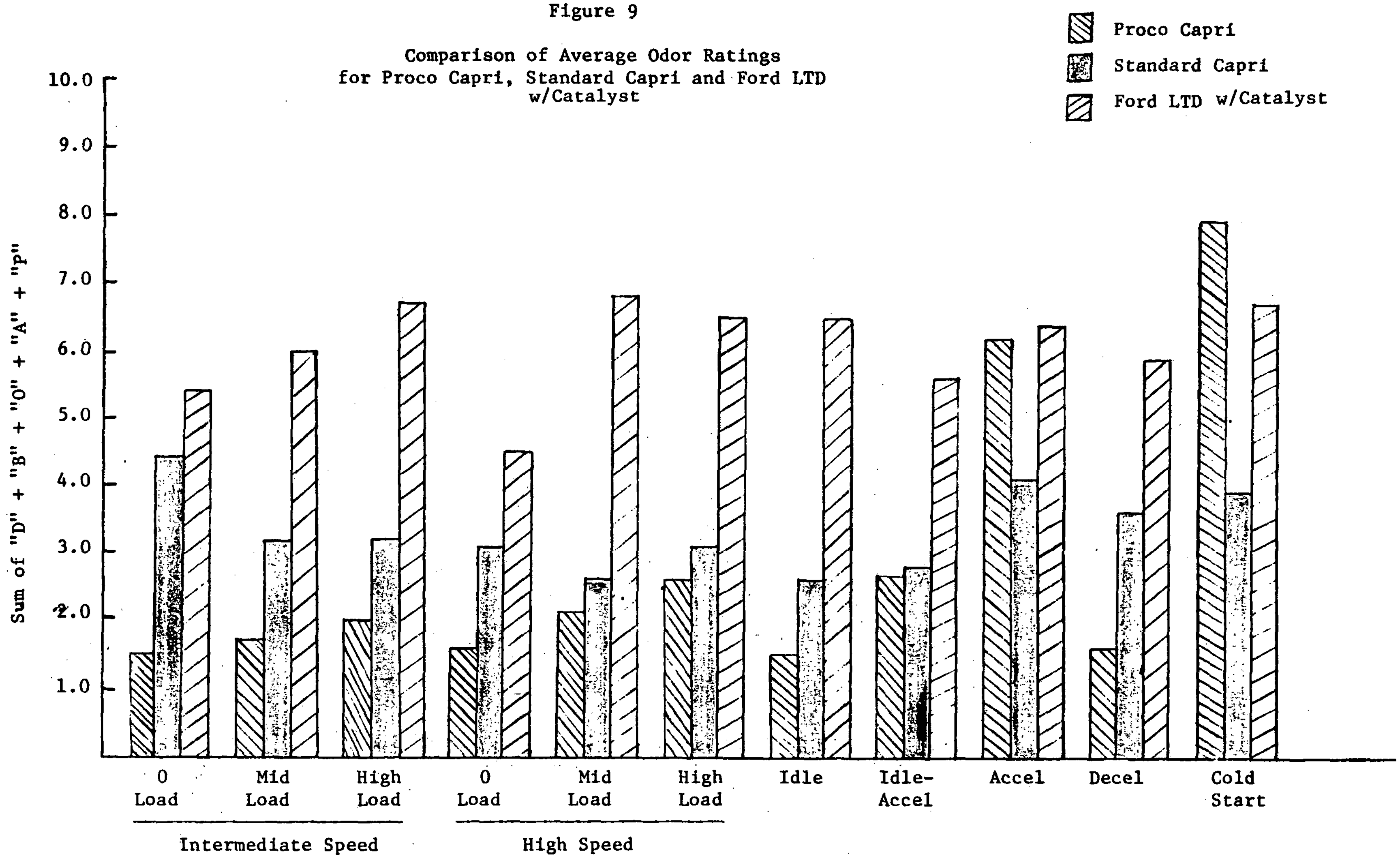

TABLE 8 EXHAUST ANALYSES TAKEN SIMULTANEOUSLY WITH ODOR RATINGS DURING STEADY-STATE CONDITIONS

Vehicle Condition	Exhaust Emission	Ford LTD	Capri Std.	Capri PROCO
Intermediate Speed, no load	HC, ppmC	294	1052	21
	CO, ppm	221	1.9%	3
	NO-NDIR, ppm	101	65	118
	NO-CL, ppm	95	59	109
	NO_x-CL, ppm	99	62	110
	O_2, %	7.1	3.3	5.4
	CO_2, %	10.0	11.9	11.2
	Acrolein, ppm	1.3	1.7	0
	Formaldehyde, ppm	8.1	20.9	0.8
	Aliph. Alde., ppm	21.9	60.5	9.5
	TIA	1.6	1.9	0.7
	LCA, μg/l	4	26	0
	LCO, μg/l	4.4	8.3	0.6
Intermediate Speed, mid load	HC, ppmC	318	1311	7
	CO, ppm	198	0.5%	4
	NO-NDIR, ppm	821	654	288
	NO-CL, ppm	798	541	279
	NO_x-CL, ppm	802	559	273
	O_2, %	5.9	3.6	2.2 2
	CO_2, %	10.8	12.2	14.3
	Acrolein, ppm	0.9	3.7	0
	Formaldehyde, ppm	14.6	21.9	1.0
	Aliph. Alde., ppm	30.8	57.7	7.6
	TIA	1.8	2.2	0.7
	LCA, μg/l	5	41	0
	LCO, μg/l	5.2	14.6	0.6
Intermediate Speed, high load	HC, ppmC	220	1480	8
	CO, ppm	226	0.2%	0
	NO-NDIR, ppm	1409	1707	668
	NO-CL, ppm	1354	1413	643
	NO_x-CL, ppm	1363	1467	644
	O_2, %	5.4	3.5	2.9
	CO_2, %	11.3	12.3	13.4
	Acrolein, ppm	1.8	5.0	0
	Formaldehyde, ppm	11.4	22.9	1.8
	Aliph. Alde., ppm	31.3	66.4	9.0
	TIA	1.8	2.2	0.5
	LCA, μg/l	5	39	0
	LCO, μg/l	6.3	17.9	0.4
High Speed no load	HC, ppmC	523	144	9
	CO, ppm	287	0.4%	4
	NO-NDIR, ppm	325	150	212
	NO-CL, ppm	305	119	203
	NO_x-CL, ppm	305	119	204
	O_2, %	7.2	1.3	4.8
	CO_2, %	9.8	14.2	11.8
	Acrolein, ppm	1.1	1.6	0.1
	Formaldehyde, ppm	6.5	19.7	2.2
	Aliph. Alde., ppm	27.0	51.6	8.1
	TIA	1.9	2.0	0.6
	LCA, μg/l	6	24	0
	LCO, μg/l	6.6	9.2	0.6
High Speed, mid load	HC, ppmC	102	1075	5
	CO, ppm	341	0.4%	6
	NO-NDIR, ppm	696	2473	871
	NO-CL, ppm	642	1867	831
	NO_x-CL, ppm	642	1883	831
	O_2, %	2.9	1.2	1.9
	CO_2, %	13.5	14.0	14.4
	Acrolein, ppm	0.8	4.4	0
	Formaldehyde, ppm	5.7	25.0	1.7
	Aliph. Alde., ppm	21.1	62.6	7.3
	TIA	1.4	2.2	0.5
	LCA, μg/l	3	36	0
	LCO, μg/l	4.9	14.5	0.4
High Speed, high load	HC, ppmC	63	1883	20
	CO, ppm	596	3.1	8
	NO-NDIR, ppm	696	1944	1396
	NO-CL, ppm	679	1690	1317
	NO_x-CL, ppm	679	1713	1323
	O_2, %	1.8	0.4	4.7
	CO_2, %	14.1	13.7	11.7
	Acrolein, ppm	0.9	2.4	0
	Formaldehyde, ppm	5.9	25.2	1.0
	Aliph. Alde., ppm	18.7	58.3	9.5
	TIA	1.6	2.1	1.1
	LCA, μg/l	4	53	0
	LCO, μg/l	4.0	14.8	1.3
Idle Speed, no load	HC, ppmC	116	2107	51
	CO, ppm	133	4.4%	5
	NO-NDIR, ppm	67	27	46
	NO-CL, ppm	70	22	61
	NO_x-CL, ppm	70	25	61
	O_2, %	6.1	8.3	9.2
	CO_2, %	10.7	7.2	8.1
	Acrolein, ppm	0.7	2.9	0
	Formaldehyde, ppm	8.4	18.4	1.7
	Aliph. Alde., ppm	24.2	54.7	8.3
	TIA	1.5	1.9	0.6
	LCA, μg/l	3	34	0
	LCO, μg/l	3.9	9.0	0.5

Intermediate Speed is 60 percent of high speed defined as the rpm in highest gear that coincides with 56 mph vehicle speed and level road load.

Mid load is fuel rate midway between no load (neutral) and high load fuel rates.

Ford LTD, and both Capris ran at 4 times level road load at 50 mph (full load) and 2 times level road load at 50 mph (mid load).

Table 9

Oxygenates Emissions During '75 FTP
in grams/mile (grams/kilometre)

Vehicle: Blue Proco Capri

Run No.	Aldehydes	Formaldehyde	Acrolein
1	.0130 (.0081)	.0040 (.0025)	0 (0)
2	.0130 (.0081)	.0031 (.0019)	0 (0)
3	.0117 (.0073)	.0019 (.0012)	0 (0)
4	.0140 (.0087)	.0031 (.0019)	0 (0)
Avg.	.0130 (.0081)	.0031 (.0019)	0 (0)

Table 10

Noise (dBA Scale)

		STD Capri	PROCO Capri	Mercedes 220D	Peugeot 504D	Opel 2100D	Nissan 220C
SAE J986A	Exterior	73	76	77	70.8	67.5	74.8
Accel Driveby	Interior	81.5	83	74.3	78.5	73.5	83.3
30 mi./hr.	Exterior	58.1	58.5	62	61.3	62.5	63.3
Driveby	Interior	65.8	70.5	63.5	66.5	69	69.5
Idle	Exterior	63	63.5	66	68	72	79.0
	Interior	54	66	51.5	52.3	53.3	66.8

7. Noise

Both exterior and interior noise measurements were made on the PROCO Capri, a standard Capri and four Diesel cars. The results are shown in Table 10. In all tests, the PROCO had higher noise levels than the standard Capri. The biggest differences were noted in the interior measurements, with the PROCO, at 66 dBA at idle, being 12 dBA higher than the standard Capri. The highest noise level recorded for the PROCO was an interior measurement of 83 dBA on the SAE J986A acceleration driveby. Surprisingly this was only 1.5 dBA higher than the standard Capri. The PROCO compared favorably with the Diesels on exterior measurements but was in nearly all instances higher in interior noise levels.

8. Particulate Emissions

The results of the total particulates collected during a 1975 FTP are shown in Table 11. For this test the catalytic reactor was removed from the PROCO Capri. The PROCO's total particulate emission of 0.10 gram/mile, was twice that of the 1975 prototype LTD with catalyst with unleaded gasoline. However this value was considerably below the .25 gram/mile particulates emitted from a typical gasoline engine running on leaded gasoline or a low smoke level Diesel car.

9. Sulfate Emissions

The sulfate emissions were measured on the white Proco Capri over the 75 FTP, 72 FTP (hot start), and Highway cycles and at 60 mph steady state road load. The results are presented in Table 12. The sulfate emissions as sulfuric acid ranged from 3.4 to 6.9 milligrams per mile. Conventional engines with oxidation catalysts have sulfate emissions ranging from 5 to 100 milligrams/mile. Generally the catalyst cars without secondary air injection (i.e. air pumps) emit at the lower level, while those with secondary air injection emit at the higher level. Non-catalyst cars typically have sulfate emissions of 1 milligram per mile. Thus the Proco Capri appears to emit at the levels typical of catalytically controlled engines without air pumps. This is somewhat surprising since the oxygen content of the Proco exhaust before entering the catalyst is higher than that of catalyst cars with secondary air injection (due to the extremely lean A/F ratios of the Proco). A partial explanation is the lower fuel consumption of the Proco Capri. That is since its mass consumption per mile of sulfur is less its mass emissions per mile of sulfates is lower.

Table 11

Particulate Emission Test Results

	1975 FTP		1972 FTP (Hot Start)		60 MPH Steady State		Dominant*
	gm/mi	(gm/km)	gm/mi	(gm/km)	gm/mi	(gm/km)	Constituent
Blue PROCO Capri w/thermal reactor (no catalyst)	0.10	(0.06)	0.06	(0.04)	0.06	(0.04)	--
Typical 1975 Prototype gasoline w/o Pb	0.05	(0.03)	0.02	(0.01)	0.03	(0.02)	51%
Typical Engine with leaded fuel	.25	(0.15)	--	--	--	--	35% Pb
Datsun-Nissan 220C Diesel	0.30	(0.19)	0.30	(0.19)	--	--	73% C

*Particulate analyzed for: Fe, Ni, Cu, Al, Ca, Mg, Mn, Cr, Sn, Ti, Pb, C, H, N

Table 12

Sulfate Test Results
on White Capri with .033% Fuel Sulfur

Test	No. of Tests	Total Particulates milligrams/mile ± milligrams/kilometre	Sulfuric Acid milligrams/mile ± milligram/kilometre	% Fuel Sulfur converted to Sulfate
1975 FTP	1	27.1 (16.8)	3.7 (2.3)	3.2
1972 FTP (hot Start)	4	32.7 ± 4.6 (20.3 ± 2.8)	4.3 ± 1.0 (2.6 ± 0.6)	3.8 ± 1.0
Highway Cycle	6	18.4 ± 2.5 (11.4 ± 1.6)	3.4 ± 0.6 (2.1 ± 0.4)	4.0 ± 0.8
60 mph Steady State	10	22.6 ± 5.1 (14.0 ± 3.2)	6.9 ± 1.9 (4.3 ± 1.2)	8.8 ± 2.8

Conclusions

1. The PROCO stratified charge engine in the state of its development represented by the modified L-141 jeep engines appears quite capable of meeting the 1977 statutory levels for HC (0.41 gm/mile), CO (3.4 gm/mile) and NOx (2 gm/mile) at low mileage. The PROCO powered jeep had emissions that were within the 1978 statutory levels of 0.41 gm/mile HC, 3.4 gm/mile CO, and 0.4 gm/mile NOx. The jeep is one of the few vehicles tested by EPA to achieve 0.4 NOx without catalytic control of NOx. A major advantage of the PROCO engine is its inherently low NOx emissions from stratified charge combustion plus its high EGR tolerance. While not evident from the Table 3 data, the principle trade-off associated with NOx control in the PROCO engine is HC emissions. Lower NOx levels are only achieved with higher HC emissions in this version of the engine. Measures that may be necessary to keep HC emission low at high mileage (e.g. injection and timing retard, increased throttling) can reduce the fuel economy achievable. Further research may eliminate the HC problem currently experienced by this engine at very low NOx levels. Any developments that permit less throttling (currently needed for HC control even at high NOx levels) will improve this engine's economy potential. Durability experience on other PROCO engines of this generation indicates that .41 HC and 3.4 CO levels cannot be maintained for 50,000 miles with a 0.4 NOx calibration without catalyst changes.[1]

2. The average fuel economies of the blue and white PROCO Capris (23.9 and 23.5 mpg respectively on the 75 FTP) exceeded, by over 5 mpg, the average fuel economy (18.4 mpg) of all 1975 Federal certification vehicles in the 2750 inertia weight class. In fact they exceeded the best fuel economy (21.2 mpg) achieved in the 2750 IW class. This good fuel economy coupled with their low emission levels, demonstrate the PROCO's capability of meeting stringent emission levels without sacrificing fuel economy relative to standard gasoline engines.

3. The Heavy Duty cycle for gaseous emissions indicated that the PROCO Capri has high HC and CO emissions during sustained W.O.T. conditions. This suggests that the A/F ratio at this condition was too rich to provide sufficient oxygen to adequately oxidize the HC and CO. Since the Proco Capri required little W.O.T. operation on the '75 FTP, this mode of operation had a negligible affect on the Capris emissions on the LDV cycle.

---

[1] Choma, M. and Simko, A. "Programmed Combustion Process (PROCO) (Ford Combustion Process) Final Technical Report." March 1973. Contract No. DAAE07-70-C-4374 with U.S. Army Tank-Automotive Command

4. The Smoke, Odor, Oxygenate, and Particulate emissions testing all indicated that the PROCO's emissions in these categories are equal to or less than those of standard gasoline engines. Thus the PROCO may have no trouble in these areas in terms of public or legal acceptance unless further research determines more deleterious health effects per gram of unregulated emission than for conventional engine exhaust.

5. The noise testing showed the noise levels of the PROCO Capri to be higher than a standard Capri. The exterior noise levels were only moderately higher (.4 to 2.9 dBA higher), but the interior noise levels of the PROCO were as much as 12 dBA higher (at idle) than the standard Capri. Compared to a Mercedes 220D Diesel car, the PROCO's exterior noise level was lower, while its interior noise level was greater. In fact the interior noise levels of the standard Capri were higher than those of the 220D. Since it appears from external noise measurements that the PROCO engine is no noisier than the 220D Diesel engine, existing soundproofing techniques should allow for the reduction of the interior noise level to that of the Mercedes 220D.

6. The sulfate emissions of the Proco Capri are of the order of 5 milligrams per mile. While this is at the lower end of the range of sulfate emissions emitted by conventional engines with catalysts it may still be of some concern. Sulfate emissions standards for light duty vehicles are planned by EPA for model year 1979. It remains to be seen if the Proco's sulfate emissions will exceed that standard.

Appendix 1

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1973 Ford Capri
Emission control system - Programmed S/C Combustion (PROCO)

Engine

type	4 stroke, stratified charge Otto Cycle, OHV, in-line 4 cylinder
bore x stroke	3.875 x 3.00 in./98.4 x 76.2 mm
displacement	141.5 cu in./2320 cc
compression ratio	11:1
maximum power @ rpm	approx. 71 bhp/ 53 kw @ 4000 rpm
fuel metering	direct fuel injection
fuel requirement	91-96 RON unleaded used, octane requirement unknown

Drive Train

transmission type	4 speed manual
final drive ratio	3.44:1

Chassis

type	unit body, front engine, rear wheel drive
tire size	165 SR 13
curb weight	2300 lb/1045 kg
inertia weight	2500 lb
passenger capacity	4

Emission Control System

basic type	charge stratification
oxidation	close coupled to exhaust manifold outlet
catalyst substrate	monolith-American Lava w/Mathey Bishop coating
catalyst volume.	118 in^3
thermal reactor type	low thermal inertia exhaust manifold
exhaust gas recirculation	8% (1 gm NOx standard)
additional features	Altitude compensated A/F ratio control plus Ford transistorized ignition
durability accumulated on system .	650 mi/1047 km - blue Capri 1100 mi/1770 km - white Capri

Vehicle I.D. No.

white Proco Capri	GAE CNP 26116
blue Proco Capri	GAE CNP 65954

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1973 Ford Capri
Emission control system - Engine Modification

Engine

type	4 stroke, Otto cycle, OHV, In-line 4 cyl
bore x stroke	3.6 x 3.0 in./(91 x 76 mm)
displacement	122 cu in./(2000 cc)
compression ratio	8.2:1
maximum power @ rpm	85 bhp/64.2 Kw @ 5400 RPM
fuel metering	2 bbl Holley carburetor
fuel requirement	91 RON unleaded

Drive Train

transmission type	4 speed manual
final drive ratio	3.44:1

Chassis

type	2 door sedan, front engine, rear drive
tire size	165 SR 13
curb weight	2500 lb /1130 kg
inertia weight	2750 lb
passenger capacity	4

Emission Control System

basic type	E.M.
durability accumulated on system	1385 mi/(2234 km)

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1973 Ford LTD
Emission control system - Catalyst, E.G.R., A.I.R.

Engine

type	4 stroke Otto Cycle, OHV, V-8
bore x stroke	4.00 x 4.00 in./ 102 x 102 mm
displacement	400 cu in./6550 cc
compression ratio	8.4:1
maximum power @ rpm	172 bhp/ 128 kw @ 4000 rpm
fuel metering	2V carburetor
fuel requirement	91 RON unleaded

Drive Train

transmission type	3 speed automatic
final drive ratio	2.75:1

Chassis

type	body/frame, front engine, rear wheel drive
tire size	HR 78-15
curb weight	4,300 lb./ 1955 kg
inertia weight	4500 lb./ 2,045 kg
passenger capacity	6

Emission Control System

basic type	oxidation catalyst, air injection, exhaust gas recirculation
mileage on vehicle at start of test program	9130 mi./14,700 km

TEST VEHICLE DESCRIPTION

Chassis model year/make - M151 ¼ ton "Jeep"
Emission control system - Programmed S/C Combustion (PROCO)

Engine

type	4 stroke, Otto cycle, OHV, in-line 4 cyl.
bore x stroke	3.875 x 3.00 in./98.4 x 76.2 mm
displacement	141.5 cu in./2320 cc
compression ratio	11:1
maximum power @ rpm	approx. 71 bhp/53 kw @ 4000 RPM
fuel metering	low pressure (300 psi) cylinder injection
fuel requirement	91-96 RON unleaded used, octane requirement unknown

Drive Train

transmission type	4 speed manual
final drive ratio	4.86:1

Chassis

type	2 door, front engine, rear drive
tire size	700 x 16
curb weight	
inertia weight	2750 lb./ 1250 kg
passenger capacity	3

Emission Control System

basic type	stratified charge, exhaust gas recirculation, low thermal inertia exhaust manifold, close coupled monolith catalyst, positive crankcase ventilation

Appendix II

1. 1975 Light Duty Vehicle Gaseous Emissions FTP

The cold start 1975 FTP was the basic gaseous transient procedure used. Described in the Federal Register of November 15, 1972, this test is conducted on a chassis dynamometer and employs the Constant Volume Sampling (CVS) procedures. Exhaust emissions of HC, CO, NOx, and CO_2 are reported in grams per mile and fuel economy is calculated by the carbon balance method. This driving cycle has an average speed of 20 mph and is representative of urban traffic patterns.

2. Highway Cycle Testing

Described in the EPA Recommended Practices for conducting Highway Fuel Economy Tests, this cycle simulates a hot start 10.2 mile trip in a non-urban area. With an average speed of 48 mph, fuel economies achieved on this test are near the optimum achievable for normal long distance travel. This test employs the same test equipment as the '75 FTP and yields exhaust emissions in grams per mile as well as fuel economy.

3. 13-Mode Heavy Duty Vehicle Gaseous Emissions

The 1974 Heavy Duty gaseous emissions test for Diesel engines known as the 13-mode test, is a stationary engine test. The 39-minute long chassis version of this procedure is a speed-load map of 13 modes, at 3 min per mode. In addition to CO and NO by NDIR (according to SAE recommended practice J-177), and HC by heated FID (according to SAE recommended practice J-215), air rate must be measured continuously (according to SAE recommended practice J-244). A Flo-Tron system was used to measure the net fuel consumption of the engine, which, in turn, enabled the use of manufacturer's curves for inlet fuel rate and engine flywheel horsepower to set power points.

The Proco stratified charge engine had a rated speed of 4000 rpm and nominal peak torque speed of 2400 rpm. For the 13-mode test, the intermediate speed is defined as peak torque or 60 percent of rated, whichever is higher. The procedure starts with low idle, then 2, 25, 50, 75, and 100 percent load at intermediate speed followed by low idle. Then speed is increased to rated at 100 percent load with decrease to 75, 50, 25, and 2 percent. Another idle is then run.

The major difference between the stationary test used for certification and the chassis alternative is the procedure used to determine the engine operating points at 25, 50, and 75 percent of power and the actual power output at 100 percent. The stationary 13-mode procedure uses measured power output at the flywheel to determine the cycle weighted power for division into the product of emission concentration times density of emission times flow exhaust to get brake specific emission rate. For engines installed in a chassis, there is no convenient way to measure power output at the flywheel. But, it is convenient to measure the net fuel rate to the engine which can be used to determine power, given suitable curves from the manufacturer.

For most of the cars subjected to this test, a curve of fuel rate versus flywheel power output, from no load to maximum power output at rated and intermediate speed was available. The procedure was to measure maximum fuel rate by operating at maximum power output at each specified speed. The flywheel power output for the maximum fuel rate was read from the available curve. The part load power fuel rate settings were then obtained from the curve at 75, 50, and 25 percent of the maximum chassis dynamometer power reading. The vehicle was then operated at these fuel rates during the test and the power used in the calculations was that read or determined by the fuel-power curves.

4. <u>1975 Light Duty Vehicle FTP - Smoke</u>

There currently is no recognized U.S. smoke test procedure for light duty passenger car exhaust. Although the Heavy Duty schedule can be used with the light duty vehicle by a chassis dynamometer version of the test, it is uncertain whether this test is indeed representative of the way the smaller, higher speed engines operate. The smoke opacity was recorded therefore, during operation of the vehicle over the LA-4 transient driving schedule used for the Federal light duty gaseous emissions test. The U.S. EPA light extinction smoke meter was connected at the end of the tailpipe and continuously recorded smoke opacity throughout the test cycle. Smoke tests were conducted independently of the emission tests.

5. <u>Light Duty Vehicle - Odor</u>

(a) Diesel Odor Evaluation by Trained Panel

The EPA (PHS) quality-intensity (Q/I) or Turk kit method of evaluation of dilute samples of Diesel exhaust odor was employed to express odor judgements by the trained ten-person SwRI odor panel. The kit includes an overall "D" or composite odor graded in steps of 1 through 12, 12 being strongest. The "D" odor is made of four sub-odors or qualities. These comprise burnt-smoky "B", oily "O", aromatic "A", and pungent "P" qualities. Horizontal exhaust at bumper height from a city bus was found to be diluted to a minimum reasonable level of 100:1 before being experienced by an observer. This dilution level was used in the odor test.

Both steady state and transient vehicle operation were simulated for odor evaluation. The steady state runs were made at three power levels, normally zero, one-half, and full power at a high and at an intermediate speed. The seventh condition was a low idle of a well warmed-up engine.

(b) Diesel Odor Analytical System

As one result of approximately five years of research, sponsored under the CAPE-7 project of CRC APRAC, A.D. Little developed a prototype liquid chromatograph for use in predicting Diesel exhaust odor. Called DOAS for Diesel odor analytical system, the system provides two results, one being an indication of the oxygenate fraction called LCO for liquid chromatograph oxygenates, and the other called LCA for liquid chromatograph aromatics. These were found by earlier research by ADL to represent the major odorants in Diesel exhaust. The ADL studies had shown a correlation of the TIA (total intensity of aroma) to sensory measurements by the ADL odor panel TIA is equal to $1 + \log_{10}$ LCO, where LCO is expressed in μg/ℓ of the exhaust gas fraction.

Both LCO and LCA are expressed in mirco-grams per litre of exhaust using either the test fuel or a reference component for calibration. The LCO is, by virtue of its use to express TIA, considered the most important indication of Diesel exhaust by this method.

DOAS values with the trained odor panel on the vehicles in this study were obtained simultaneously. The DOAS does not measure odor, but measures a class of odorants and it was intended and developed specifically for use with Diesel exhaust. Its application to exhaust from gasoline engines had never previously been attempted. To obtain DOAS samples requires each test mode to be extended. Double the running time, from a nominal three minutes to six minutes, was needed to allow a full five minutes of trapping. The first minute is to achieve a stable operating speed and load. Panel evaluation is normally during the third minute of the run.

The odor measurement procedures applied to the Proco powered Capri were based on the extensive previous work with Diesel exhaust odor measurement from larger size vehicles. One important change was made, however, and that was to operate the car more nearly as it might on the road. This meant changing the engine speeds from rated and intermediate, as defined for the 13-mode test, to lower speeds. High speed was defined as the engine rpm corresponding to 90.1 km/hr (56 mph) level road load. The level road load power defined for this specific car test weight was set in the dynamometer 80.5 km/hr (50 mph) and then the car increased in speed to 90.1 km/hr (56 mph). The car was in high gear or high range of the transmission operating at approximately 3000 engine rpm at 90.1 km/hr (56 mph). The intermediate speed was then defined as 60 percent of this speed, which was a nominal 1800 rpm for most cars.

The basic philosophy was to characterize odor over a range of loads and speeds that could be encountered and over a wide enough range to cover steep uphill + moderate trailer towing as well as the moderate load and no load conditions.

6. <u>1975 Light Duty Vehicle - Oxygenates</u>

In addition to the usual HC, CO, and NOx measurements, samples were continuously taken and collected in reagents for wet chemical analysis. These samples were withdrawn in the stainless steel pipe section connecting the exhaust dilution point (below the CVS filter box) and the inlet of the CVS heat exchanger. Multiopening stainless steel probes were used, one probe for the aldehyde-formaldehyde bubblers in series, one for the pair of acrolein bubblers in series, one for each of the three odor trapping systems for the Diesel odor analytical system (DOAS).

In the case of wet collected traps, the entire 23-minute (bags 1 and 2) and the third bag 505 sec. portion of the 1975 FTP were taken in a single collector (bubbler or trap). This was necessary to obtain sufficient sample for analysis and preclude the problem of switching after the first 505 seconds of the run (cold start bag). The chromatropic acid method for formaldehyde, 3-methyl-2-benzothiazolone hydrazone (MBTH) method for aliphatic aldehydes, and the 4-hexylresorcinal method for acrolein, all of which are wet chemical methods, were employed.

7. Vehicle Noise

This series of tests was intended to determine the maximum interior and exterior sound levels, in dBA scale, during idle and various driving modes. SAE J986a, Sound Level for Passenger Cars and Light Trucks describes a test procedure that formed the basis for measurement and vehicle operation. A General Radio Type 1933 Precision Sound Level Analyzer, General Radio Type 1562-A Sound Level Calibrator, and General Radio Wind Screen.

(a) Acceleration Drive-By

Acceleration drive-by measurements were made at 15.24 (50 feet). Each vehicle approached a line 7.6m (25 feet) before a line through the microphone normal to the vehicle path and accelerated, using the lowest transmission gear or range such that the front of the vehicle reached or passed a line 7.6m (25 feet) beyond the microphone line when maximum rated engine speed was reached. The sound level reported was that of the loudest side of the vehicle. Tests were made with all windows fully closed and the vehicle accessories such as heater, air conditioner, or defroster (radio excluded) in operation at their highest apparent noise level.

Interior sound level determinations were the same as exterior except that the microphone was located 6 inches to the right side of the driver's right ear. All other test procedures were as presented in J986a.

(b) Constant Speed Drive-By

The constant speed drive-by measurements were also made at a distance of 15.24m (50 feet). The vehicle was in high gear and driven smoothly at 48.3 km (30 mph) ± 5 percent.

Interior sound level determinations were made in the same manner as during the accel test. The sound level reported for this test was obtained in the manner outlined in the acceleration test already described.

(c) Idle

This test included sound level measurements at 3.05m (10 ft) distances from the front, rear, left (street side) and right (curb side) of the vehicle. The vehicle was parked and engine allowed to run at manufacturer's recommended low idle speed with transmission in neutral for at least one minute. Accessory items such as air conditioner or heater and defroster were not operated during this test. Interior measurements were also obtained at the same single point used in drive-by tests.

8. <u>1975 and 1972 LDV-FTP and 60 miles per hour (96.6 Km/hr) Particulate Emission Tests</u>

A Clayton CT-200-0 chassis dynamometer with a variable inertia flywheel assembly was used in all tests conducted under this program. In these tests, the vehicle was operated under approximately 60 mph road-load cruise conditions and under cyclic conditions of the Federal Test Procedure.

Exhaust particles were collected after air dilution of the exhaust in a large dilution tube. The entire exhaust stream was diluted. Air dilution and cooling of the exhaust was accomplished by a dilution tube 16 inches in diameter and 27 feet in length constructed of extruded polyvinyl chloride (PVC) pipe in several sections with butt joints which were taped during assembly prior to each run. The diluent air coming into the tube was filtered by means of a Dri-Pak Series 1100 Class II PIN 114-110-020 untreated cotton filter assembly. This filter assemply is 24" x 24" and has 36 filter socks which extend to 36 inches in length. This filter will pass particles 0.3 micron in size and smaller. Pressure drop at 600 cfm flow rate is minimal.

Exhaust was delivered to the tube via a tailpipe extension which was brought into the bottom of the tube downstream of the filter assembly. The extension was bent 90 degrees inside the tube, thus allowing the introduction of the exhaust stream parallel to the tube axis. Within the dilution tube, along the perpendicular plane of the end of the exhaust extension was a mixing baffle which has an 8-inch center hole and was attached to the inside diameter of the tube. The baffle presented a restriction to the incoming dilution air in the same plane as the end of the exhaust extension and provided a turbulent mixing zone of exhaust gas and dilution air.

The particulate sampling zone is located at the exhaust end of the dilution tube. Two sample probes were both connected to 142 mm holders fitted with 0.3 micron Gelman Type A glass fiber filter pads and vacuum pumps. A flow meter was used to monitor and regulate the flow through the filters. Sample probes sized to deliver an isokinetic sample from the dilution tube were used. The average mass from the two filters was used in determining total mass particulates sized greater than 0.3 microns. Heavy particulates which fall out in the tunnel are not considered of immediate concern since these would not normally be airborne in a normal environment.

9. 1975 and 1972 LDV-FTP, Highway Fuel Economy Cycle, and 60 miles per hour (96.6 km/hr) Sulfate Emission Tests

These tests were conducted on a Labeco electric chassis dynamometer. Sulfates were collected after air dilution of the exhaust in a large dilution tube 20 feet long and 18 inches in diameter, constructed of stainless steel. The diluent air was treated by filters and activated charcoal per the Federal Register procedure description of the CVS system for light duty vehicles.

The total exhaust was delivered to the dilution tube, mixed with the diluent air by a baffle and then isokenetically sampled in the tube about 12 feet downstream of the baffle. The diluted exhaust sample was filtered through Fluoropore filter having a 1.0 μ pore size.

The sulfates were extracted from the filter with an isopropyl alcohol water solution. The solution was passed through a barium chloranilate column in a high pressure liquid chromatograph where sulphate ions were quantitatively replaced with chloranilate ions. The chloranitate ions were measured colorimetrically at 310 microns. As the chloranilate concentration equalled the sulfate, quantities as small as 5 micrograms could be analyzed.

Appendix III

'75 FTP Ind. Bag Results
Mass Emissions gram/mile Fuel Economy mile/gal.

		Bag 1 Cold Transient					Bag 2 Hot Stabilized					Bag Hot Transient							
Test No.	Inertia Weight	HC	CO	CO_2	NOx	Fuel Eco.	HC	CO	CO_2	NOx	Fuel Eco.	HC	CO	CO_2	NOx	Fuel Eco.	Ambient Temp. (°F)	Rel. Hum.	Bar. Press. (inches Hg)
Blue Capri																			
15-58	2750	0.54	1.17	366	1.73	24.0	0.03	0.05	401	1.31	22.1	0.08	0.19	336	1.71	26.3	73	43	29.32
16-1131	2750	0.67	3.04	367	1.84	23.7	0.02	0.04	413	1.25	21.5	0.05	0.69	329	1.53	26.9	70.8	51	28.22
White Capri																			
15-17	2750	0.59	2.52	375	1.16	23.3	0.02	0.05	385	0.74	23.1	0.07	0.09	327	0.94	27.1	70.5	42.5	29.26
15-156	2750	0.80	3.99	343	0.42	25.2	0.08	0.04	422	0.80	21.0	0.08	0.11	358	1.06	24.7	73.5	33.5	28.85
15-4043	2750	0.62	3.27	374	1.03	23.3	0.04	0.07	425	0.68	20.9	0.06	0.09	323	0.90	25.9	74.5	37.5	29.32
15-4055	2500	0.62	3.81	373	1.08	23.3	0.04	0.04	422	0.64	21.0	0.07	0.06	344	0.92	25.7	73.5	42.5	29.25
15-4089	2500	0.54	3.36	362	1.10	24.1	0.04	0.02	411	0.32	21.6	0.09	0.10	345	0.94	26.5	69.0	49	29.02
Jeep # 3																			
12-2123	2750	0.94	0.59	418	0.30	21.05	0.04	0.56	435	0.27	20.4	0.07	0.33	379	0.24	23.4	78	64	29.67
18-120	2750	1.03	0.32	444	0.28	19.8	0.05	0.21	454	0.24	19.8	0.06	0.10	424	0.27	20.91	78	49	29.61
18-124	2750	1.02	0.43	460	0.57	19.13	0.07	0.34	443	0.25	20.0	0.06	0.06	419	0.44	20.10	75	44	29.18
18-125	2750	0.81	0.38	435	0.58	20.26	0.05	0.10	458	0.25	19.4	0.06	0.12	420	0.53	21.10	77	58	29.30
18-127	2250	0.98	0.46	465	0.45	18.9	0.02	0.33	464	0.21	19.1	0.06	0.09	413	0.36	19.7	77	42	29.18

Appendix IV

EPA Highway Cycle
Mass Emission, gram/mile Fuel Economy Miles/Gallon

Test No.	Inertia Weight	HC	CO	CO_2	NOx	Fuel Economy	Ambient Temp.(of)	Rel. Hum.	Bar. Pressure (inches Hg)
White Capri									
15-157	2750	0.01	0.01	273	0.82	32.5	70.0	37	28.87
		(0.006)	(0.006)	(170)	(0.50)	(7.24)			
15-4044	2750	0.01	0.03	288	0.71	30.8	68.0	45	29.32
		(0.006)	(0.01)	(179)	(0.44)	(7.63)			
15-4056	2500	0.01	0.03	270	0.77	32.9	65.5	53	29.25
		(0.006)	(0.01)	(168)	(0.47)	(7.15)			