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

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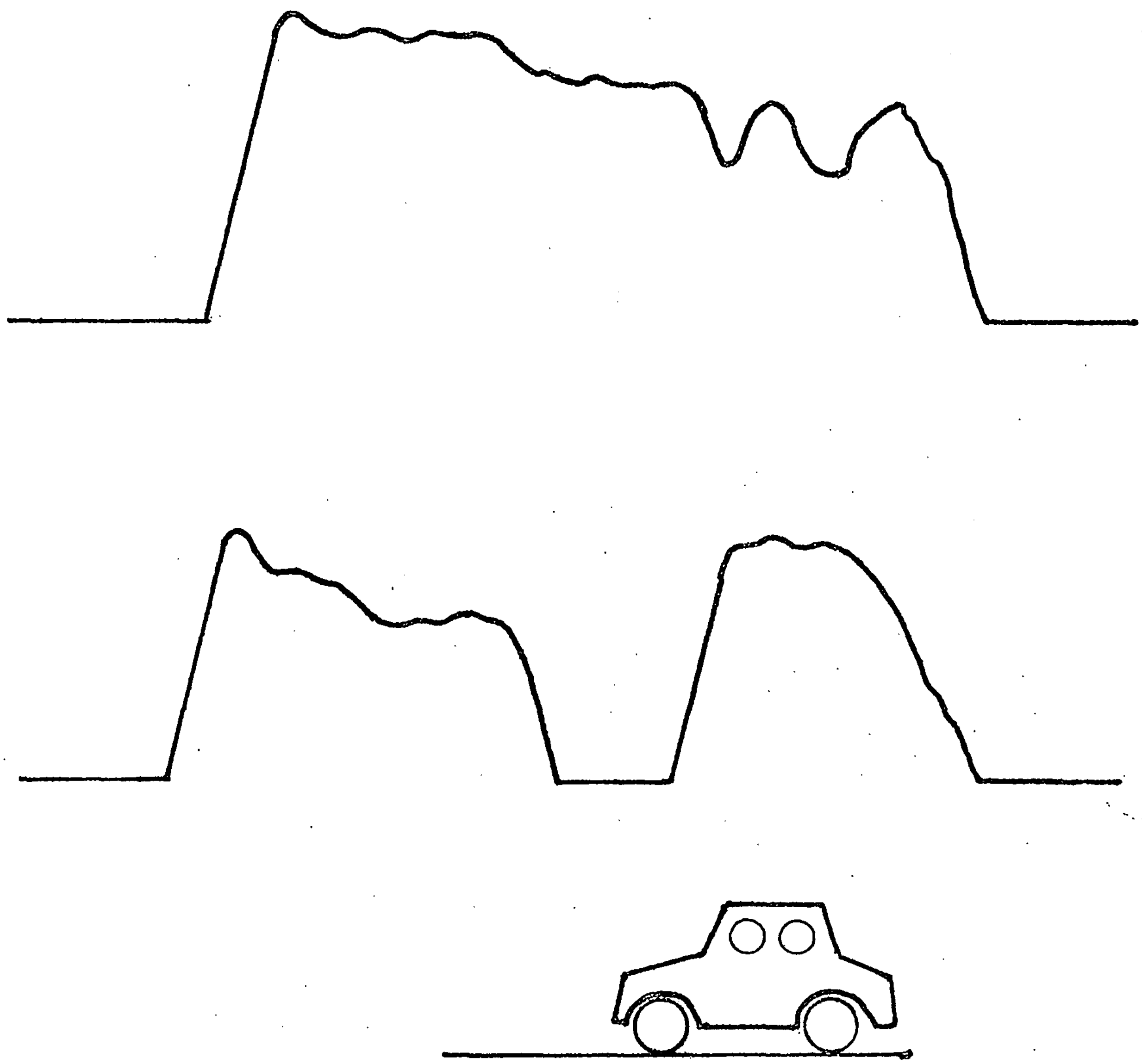

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Background

EPA has been testing vehicles for many years using the Federal Test Procedure (FTP). These procedures specify standard conditions for vehicle emission testing. Certification tests and surveilance/testing of in-use vehicles use these procedures to obtain data which can be used as input for studies of atmospheric pollution.

However, localized control strategies or specific problems often require data that is not normally generated using the standard FTP. To meet these needs specific test programs are undertaken to answer the questions raised. One recent program extensively investigated the effects of vehicle soak temperatures on emissions. To complement this effort a short test series was undertaken to quantify the probable emission effects of a modified driving cycle and the results are the subject of this report.

Specifically, this test program was designed to determine the effects of delaying vehicle warm-up. This was accomplished by substituting slow speed start-stop driving for the higher speeds normally used at the start of the standard driving cycle.

The conclusions from this EPA evaluation test can be considered to be quantitatively valid only for the specific 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 using similar emission control technology.

Abstract

For the test vehicle, a 1976 Chevrolet Impala, HC and CO emissions were found to be sensitive to the sequence in which the speed versus time profiles of the driving trace are arranged. In the case of the restructured cycle which was investigated, cold start HC emissions increased by approximately 18% because the activation of vehicle emission control systems was delayed due to reduced vehicle speeds during the initial few minutes of operation. Both cold and hot start CO emissions increased by approximately 33%. A fuel economy penalty of 7% was also observed. No change in NOx emissions was observed.

Vehicle Description

The test vehicle chosen for this project was a 1976 Chevrolet Impala with an automatic transmission. The vehicle was equipped with a two venturi, 350 CID V-8 engine. This vehicle uses a catalyst and EGR for emission control. The vehicle was a production sedan calibrated to meet the 1976 Federal Emission Standards of 1.5, 15, 3.0 grams per mile for HC, CO, and NOx respectively. The vehicle, which had been used extensively in other test programs at the MVEL, is described in detail at the end of the report. This vehicle was equipped with temperature probes for this program to monitor vehicle warm-up characteristics.

Test Procedures

Gaseous exhaust emission tests were conducted as follows: one was run using the standard urban driving cycle (UDDS) as specified in the 1977 Federal Test Procedure ('77 FTP) described in part 40 of the Combined Federal Register of July 1, 1976 and two other tests were run using the same procedure except with a modified driving cycle. No evaporative emission tests were conducted.

The tests were conducted on a chassis dynamometer and use a constant volume sampling (CVS) procedure, which gives exhaust emissions of HC, CO, CO_2, and NOx in grams per mile. Fuel economy was calculated by the carbon balance method. The fuel used was indolene clear, a no-lead 91 RON gasoline. All tests were conducted using an inertia weight of 4500 pounds (2041 kg) with a road load setting of 14 horsepower (9.5 kw) at 50 miles per hour (80.5 km/hr).

The EPA Urban Dynamometer Driving Cycle is a speed versus time schedule that is used for vehicle emission testing. This driving cycle is 7.45 miles long and takes 1371 seconds to drive. The cycle is divided into two driving segments. The first segment is 3.59 miles long and takes 505 seconds to drive. The second segment is 3.91 miles long and takes 866 seconds to drive. The first segment of this cycle is repeated following a 10 minute soak. The emissions results of each test segment are weighted together to obtain emission and fuel economy results that are representative of the vehicle's emission performance during hot and cold driving. This cycle causes the vehicle to warm up quite quickly as the freeway simulation part of the cycle occurs during the first few minutes of driving.

The modified driving cycle was designed to deemphasize vehicle warm-up. The first segment, less the initial 20 seconds of idle, was placed at the end of the second segment. Thus, in terms of the standard cycle's speed/time schedule, the modified cycle was 0 thru 20 seconds (idle), 511 thru 1366, 21 thru 505, and the last 5 seconds of idle. Thus by the end of each cycle a vehicle has travelled the same distance and has been driven similarly, although not in the same sequence. Since vehicles are usually reasonably warmed up by the end of the first 505 second segment of the test, the new cycle was split at a similar point. Thus, for both cycles, bag 1 emissions should be representative of the vehicle cold start and warm up emissions. The two cycles' characteristics are:

	Bag 1			Bag 2		
	Time	Miles	Avg. Speed (MPH)	Time	Miles	Avg. Speed (MPH)
Standard Cycle	505	3.59	25.6	867	3.91	16.2
Modified Cycle	538	2.69	18.0	834	4.76	20.6

Bag 3 is a repeat of bag 1 after a 10 minute soak of the vehicle. A driving schedule detailing each cycle is given in Figure 12.

To further quantify the emission effects of the altered driving cycle, modal emissions were taken. The modal system is a continuous exhaust measurement system which is used to calculate the pollutant emissions throughout the driving cycle. The system gives total exhaust mass emissions as well as mass emissions for each mode of the driving cycle (a mode consists of an idle, acceleration, cruise, and deceleration to zero mph). Vehicle temperatures were also monitored during the modal tests.

Test Results

Exhaust emissions data, summarized below, showed that the 1976 Chevrolet was well within the standards of 1.5 gm/mi HC, 15.0 gm/mi CO, and 3 gm/mi NOx for both driving cycles. Detailed bag results are listed in Tables I, II, and III at the end of this report.

'75 FTP Composite Mass Emissions
grams per mile (grams per kilometre)

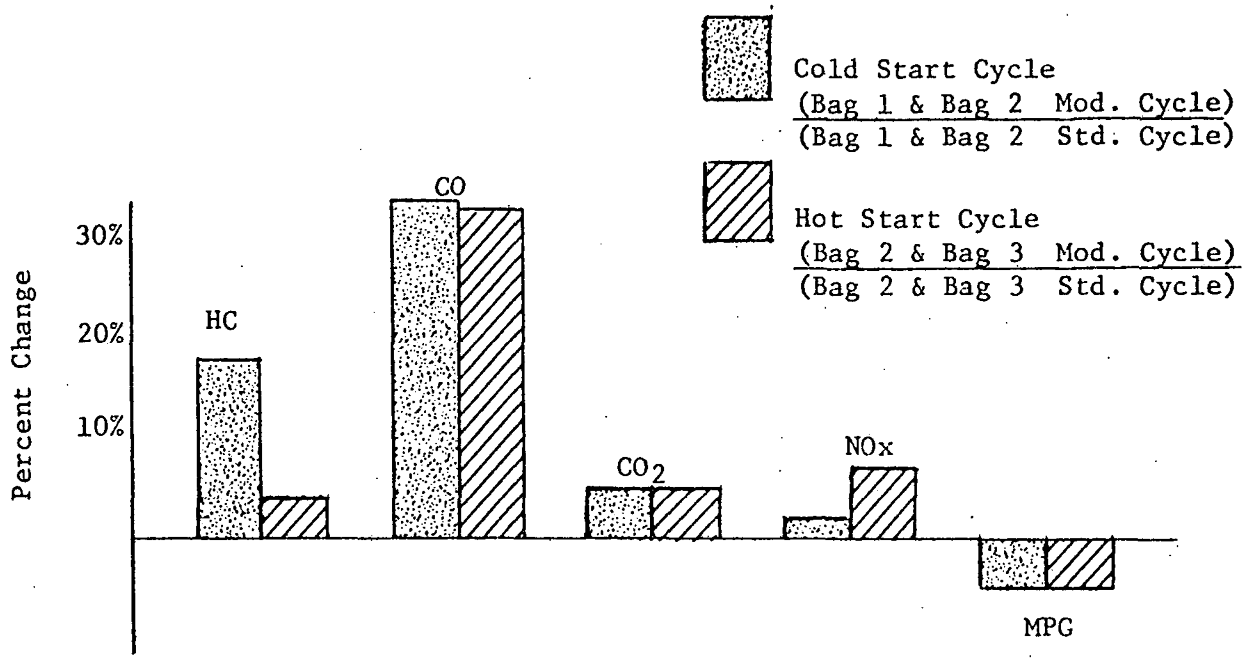
	HC	CO	CO_2	NOx	Fuel Economy
Baseline Standard Driving Cycle (1)	.48 (.30)	7.31 (4.54)	662 (411)	2.29 (1.42)	13.2 miles/gal (17.8 liters/100 km)
Modified Driving Cycle	.56 (.35)	9.85 (6.12)	699 (434)	2.41 (1.50)	12.3 miles/gal (19.1 liters/100 km)
Percentage Change (2) From Baseline	17%	35%	6%	5%	-7%

(1) Values in parenthesis denote metric units.
(2) A positive value indicates an increase in emissions or fuel economy

In both cases the driving cycles were 7.45 miles long and the calculations use the standard weightings of 43% cold driving and 57% hot driving.

Thus this vehicle showed substantial increases in HC and CO emissions with a low speed start/warm-up driving cycle. There was also a slight decrease in fuel economy. The slight increase in NOx emissions is not significant due to the data scatter.

The test data was also analyzed to determine if these effects were primarily a function of cold start. The cold start driving cycle used in Figure 1 is obtained by combining the emission results for bags 1 and 2. The hot start driving cycle consists of bags 3 and 2. The results are summarized in the following figure:



Mass Emissions
Percentage Change from Baseline Cycle

Figure 1

These cold and hot start tests show that CO emissions increase substantially with driving cycles that do not cause rapid catalyst warm up. HC emissions are increased substantially only during cold start. The effects on NOx emissions and fuel economy are smaller. The tendency is to raise NOx emissions slightly and lower fuel economy slightly.

To more thoroughly investigate the above effects, the tests were repeated using a modal analyzer system. Figures 2, 3 and 4 show the total mass emissions versus cycle miles traveled. These results reaffirm the above findings and show the effects in detail. The vehicle HC emissions are quite high on the modified cycle due to the delay in vehicle warm up. Once the emission control system becomes effective, total HC emissions increase at a very low rate. This rate of increase in total HC emission appears to be the same for both cycles. Thus, HC emissions are apparently relatively sensitive to driving patterns which delay vehicle warm up or moderate catalyst cooling.

Similarly, CO emissions are quite high due to the delay in vehicle warm up. Once the emission control systems become effective, total CO emissions increase at a very low rate. However, this rate of increase is higher than for the standard cycle. Thus, CO emissions appear more sensitive than HC emissions to cycle configuration and moderate cooling during short vehicle shut down periods.

NOx emissions are very similar for both cycles. Figure 4 shows that, although the standard cycle is initially higher in NOx, this is due to the higher initial speeds. By 7.45 miles a vehicle using both cycles has traversed the same distance and has experienced the same type of driving. At this time, the NOx emissions are substantially equal.

The modal analysis system permits the determination of catalytic convertor efficiency by measuring pollutant concentrations before and after the catalyst. Figures 5 through 8 detail the HC and CO convertor efficiency for both cycles. Figures 5 and 6 show that, at equal distances, the modified cycle shows greater efficiency. However, this is due to the greater time for warm-up, not efficiency in warming up. Figures 7 and 8 show that, for a given time, the standard cycle has warmed up the catalyst more efficiently and thereby reduced total mass emissions.

Figures 9 through 12 provide engine temperature data to further illustrate these trends. The most important difference between the two cycles is the delay in engine coolant warm up on the modified cycle. The summary table following these figures further clarifies these trends.

The effect of this modified driving cycle on other vehicle technologies is not known but can be surmised. Usually a vehicle with an air pump and a catalyst will start out with high emissions and then drop to extremely low levels for most of the FTP. Thus any delay in catalyst light off could be expected to have more detrimental effects on a vehicle with an air pump than this non-air pump equipped catalyst vehicle. Vehicles operating with lean fuel/air ratios, such as stratified charge engines, usually achieve their emission control by maintaining a relatively low emission at constant levels. Thus the effect of this modified cycle on a lean mixture vehicle would probably be minimal.

Conclusion

For a 1976 Chevrolet Impala, HC and CO emissions are sensitive to the order in which a particular driving cycle is driven. Cold start HC and CO emissions will increase about 18% and 30%, respectively if vehicle emission control system functioning is delayed by reducing vehicle speeds during the initial few minutes of operation.

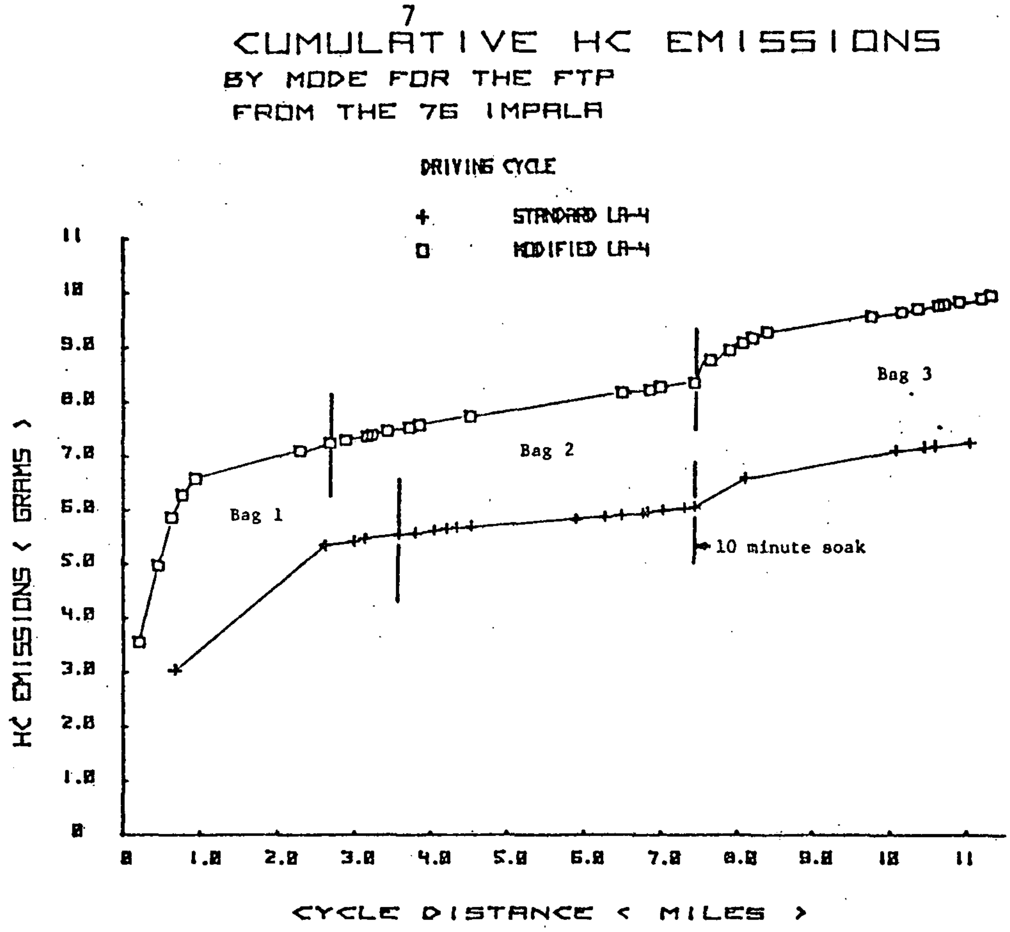


Figure 2

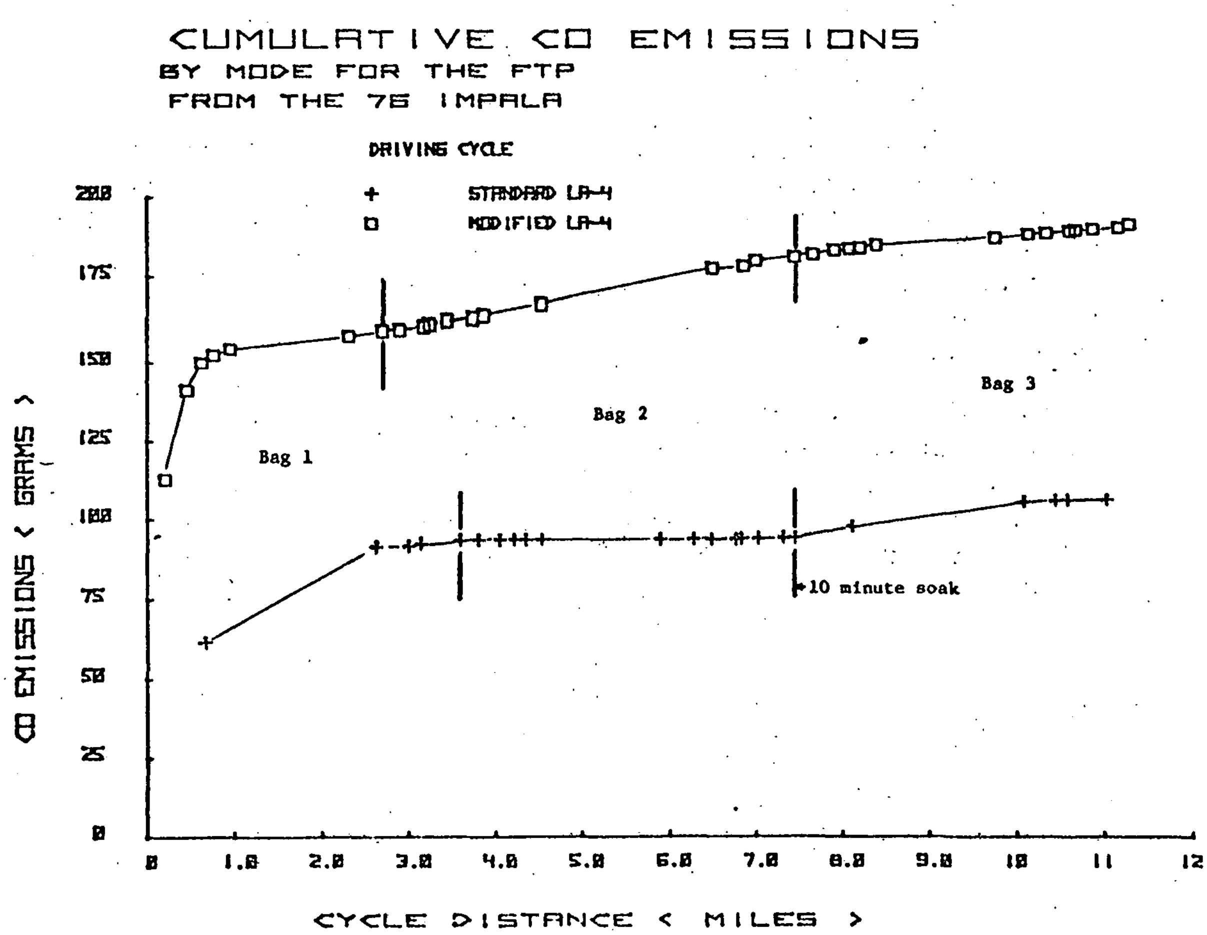


Figure 3

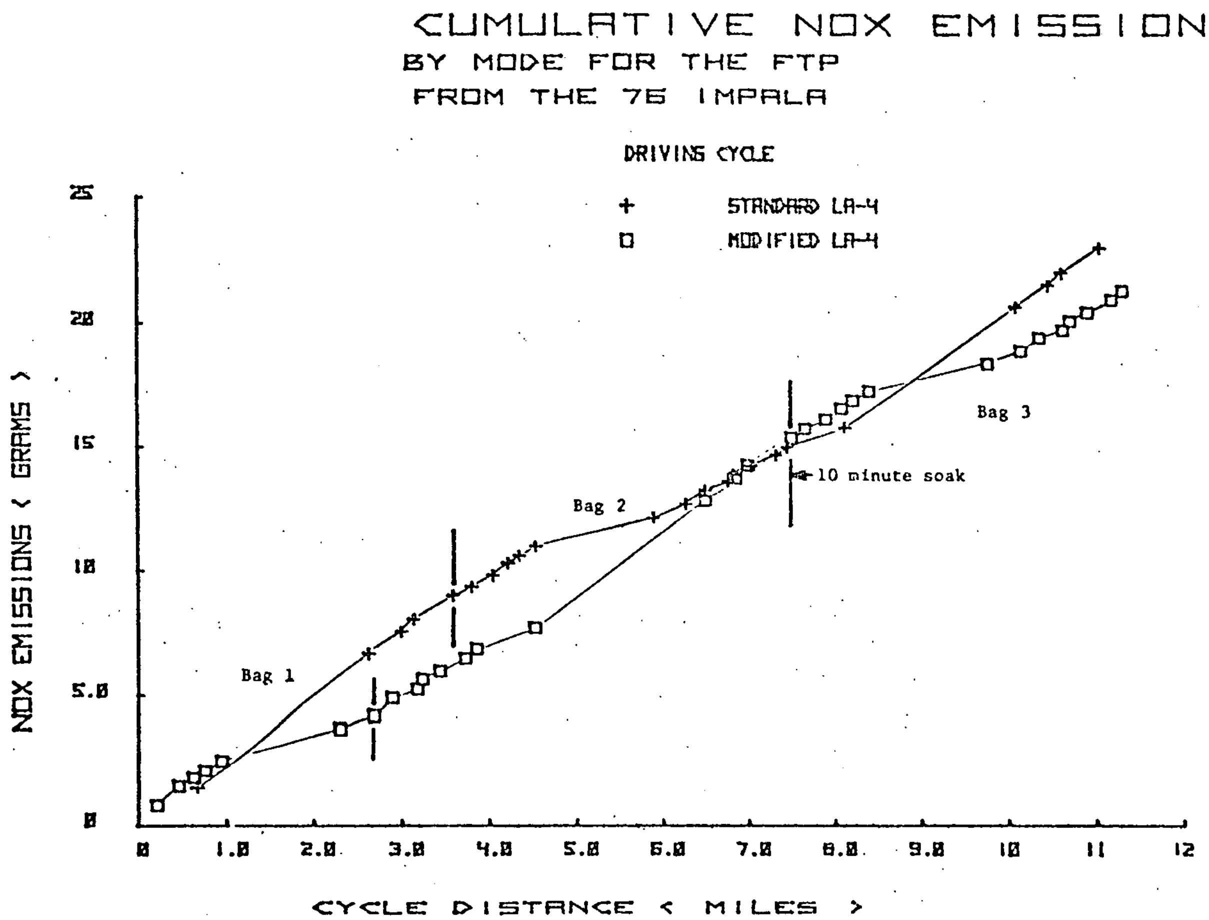

CUMULATIVE NOX EMISSION
BY MODE FOR THE FTP
FROM THE 76 IMPALA
DRIVING CYCLE
STANDARD LA-4
MODIFIED LA-4
Bag 1
Bag 2
Bag 3
10 minute soak
NOX EMISSIONS (GRAMS)
CYCLE DISTANCE (MILES)
0
5.0
10
15
20
25
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10
11
12

Figure 4

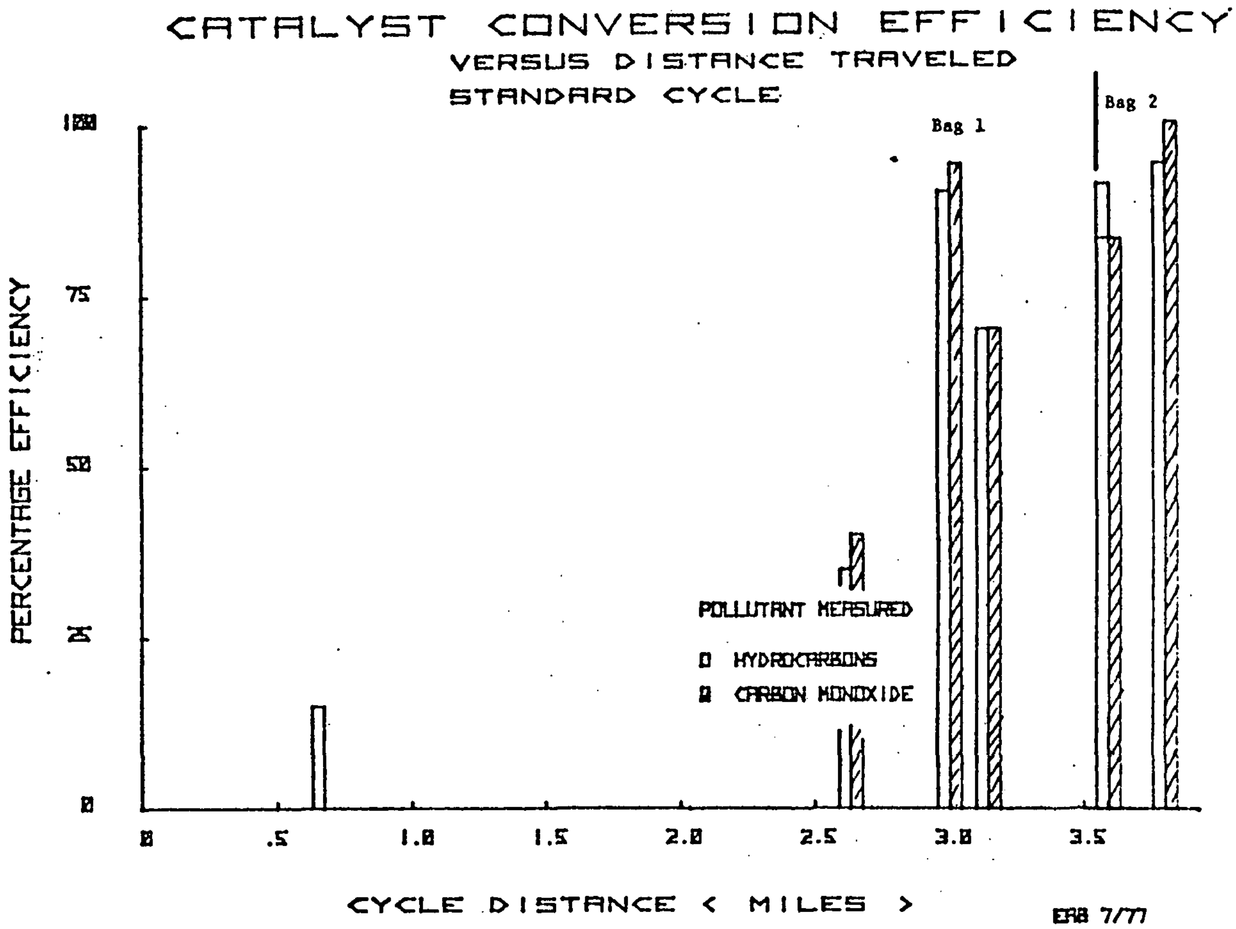


Figure 5

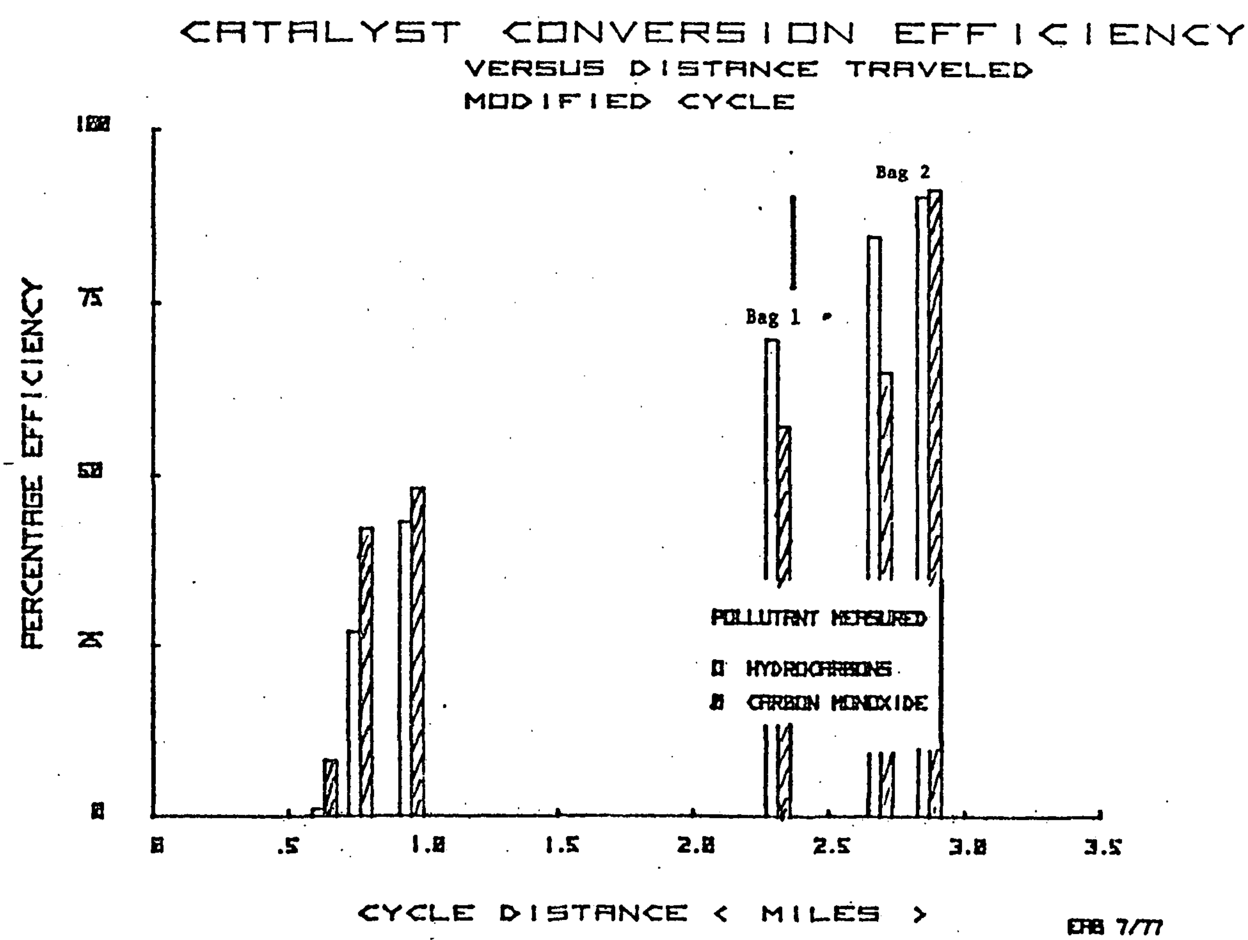


Figure 6

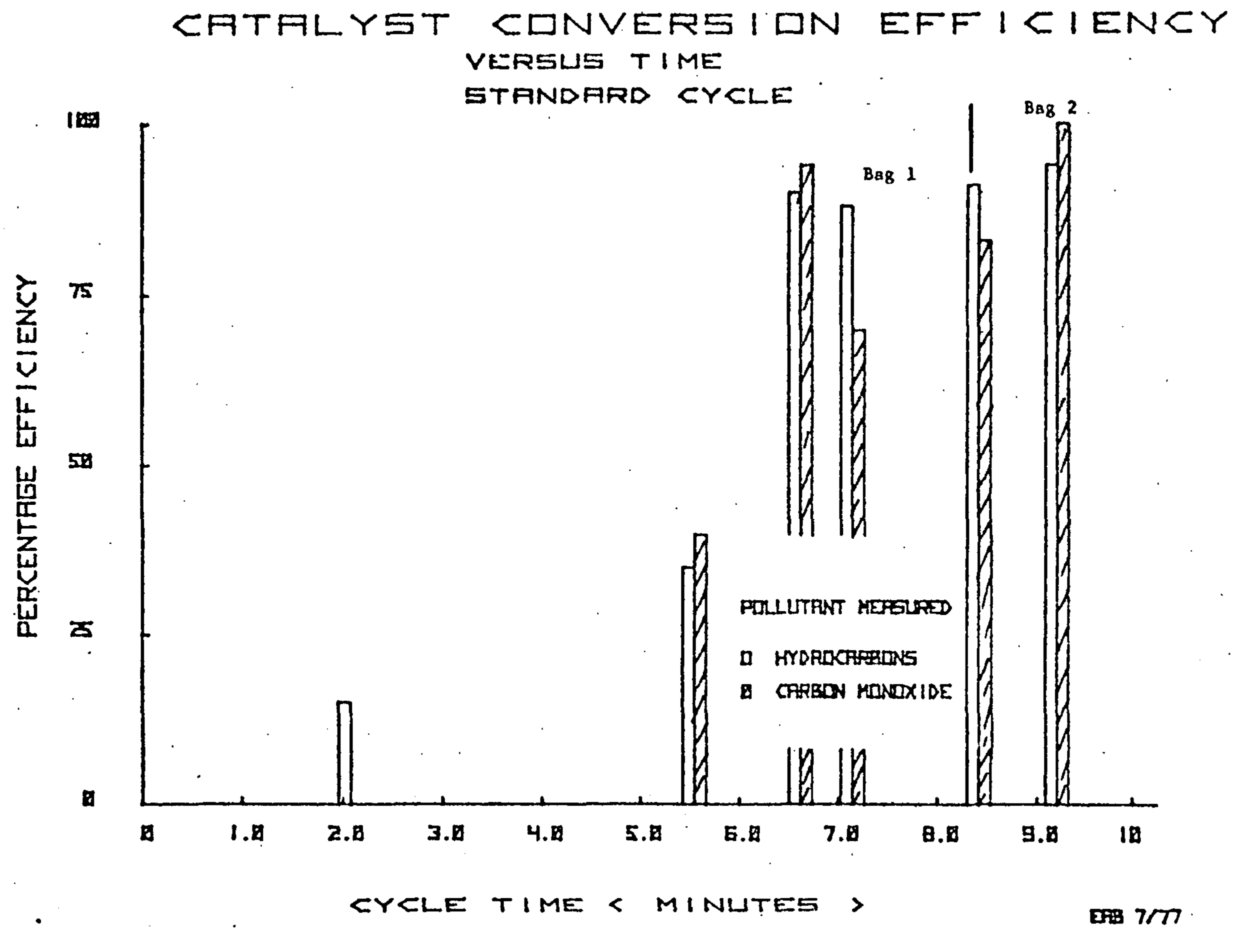
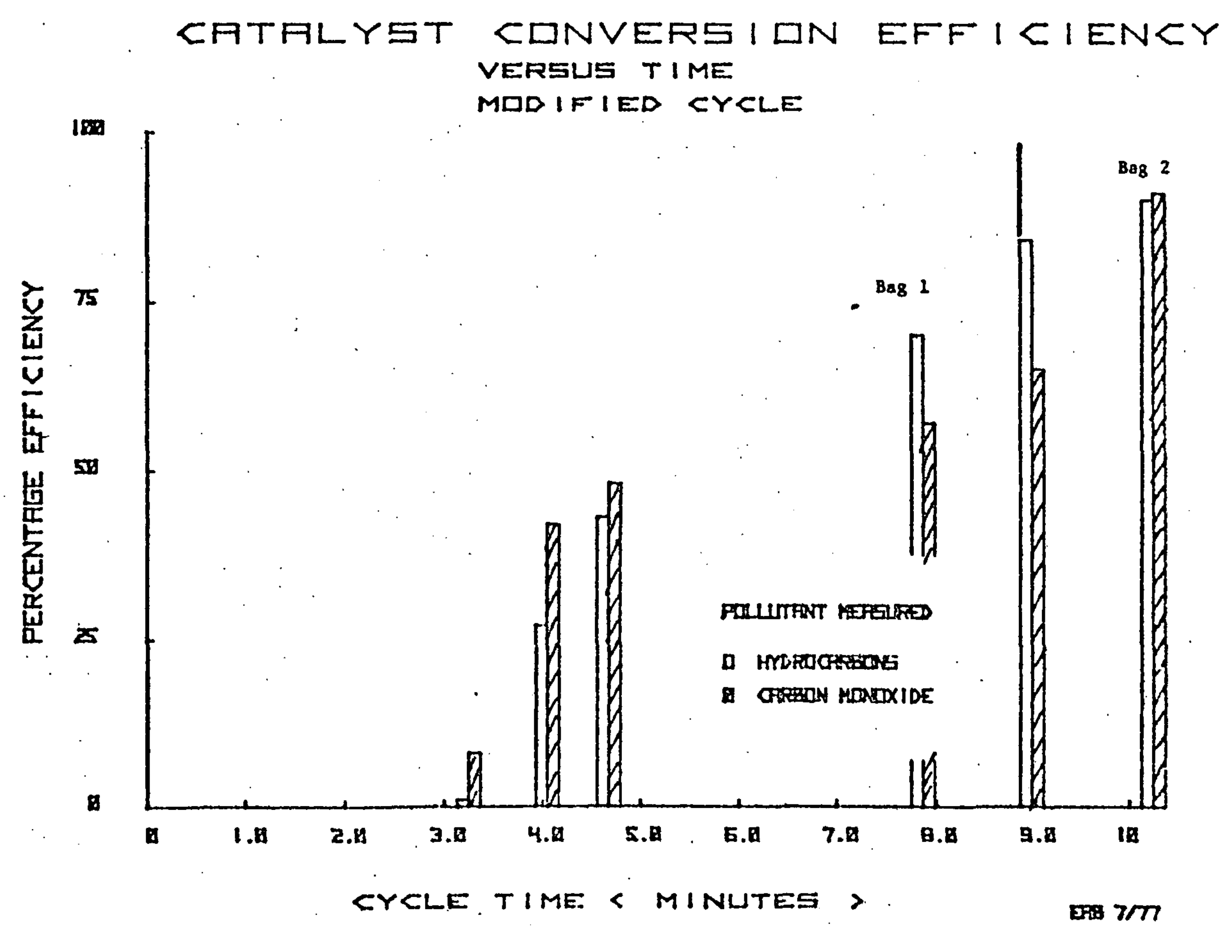

CATALYST CONVERSION EFFICIENCY
VERSUS TIME
STANDARD CYCLE
PERCENTAGE EFFICIENCY
Bag 1
Bag 2
POLLUTANT MEASURED
HYDROCARBONS
CARBON MONOXIDE
CYCLE TIME < MINUTES >
ERB 7/77

Figure 7


CATALYST CONVERSION EFFICIENCY
VERSUS TIME
MODIFIED CYCLE
PERCENTAGE EFFICIENCY
Bag 1
Bag 2
POLLUTANT MEASURED
HYDROCARBONS
CARBON MONOXIDE
CYCLE TIME < MINUTES >
ERB 7/77

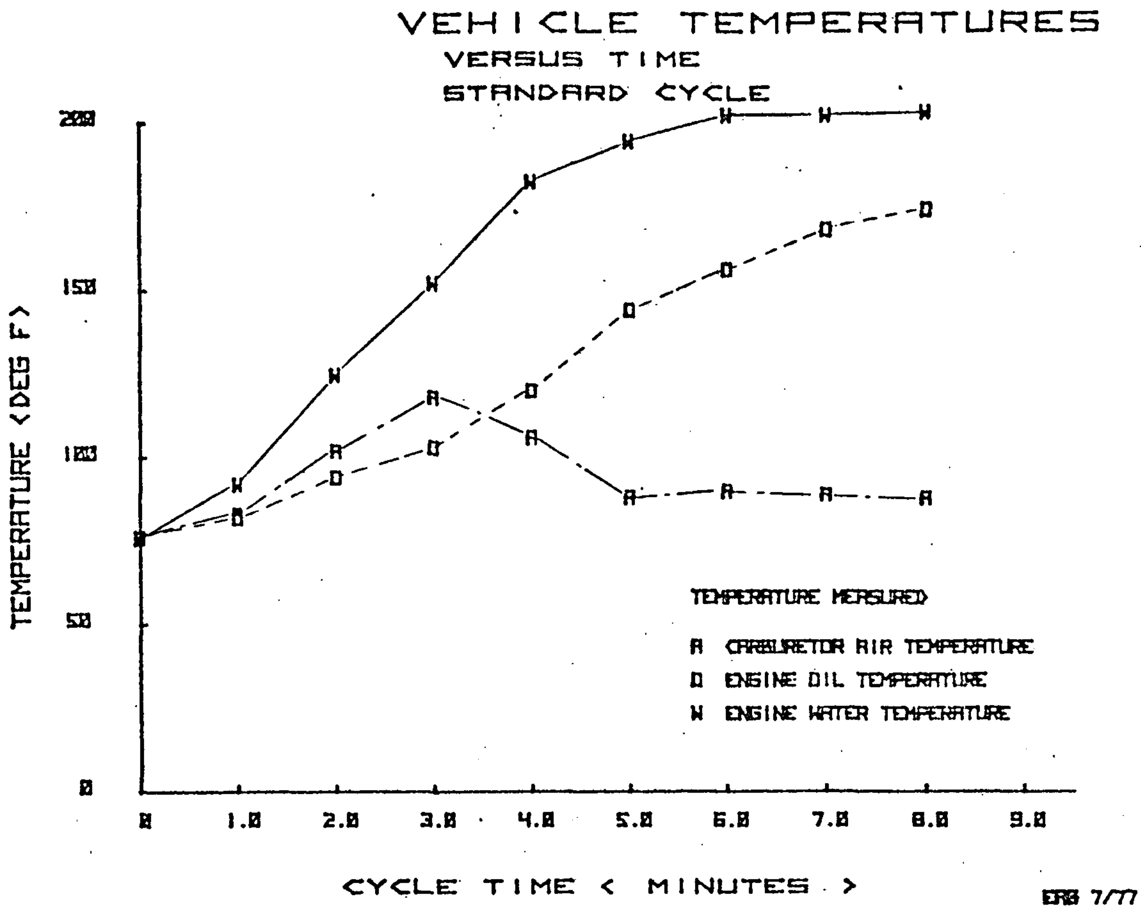


Figure 9

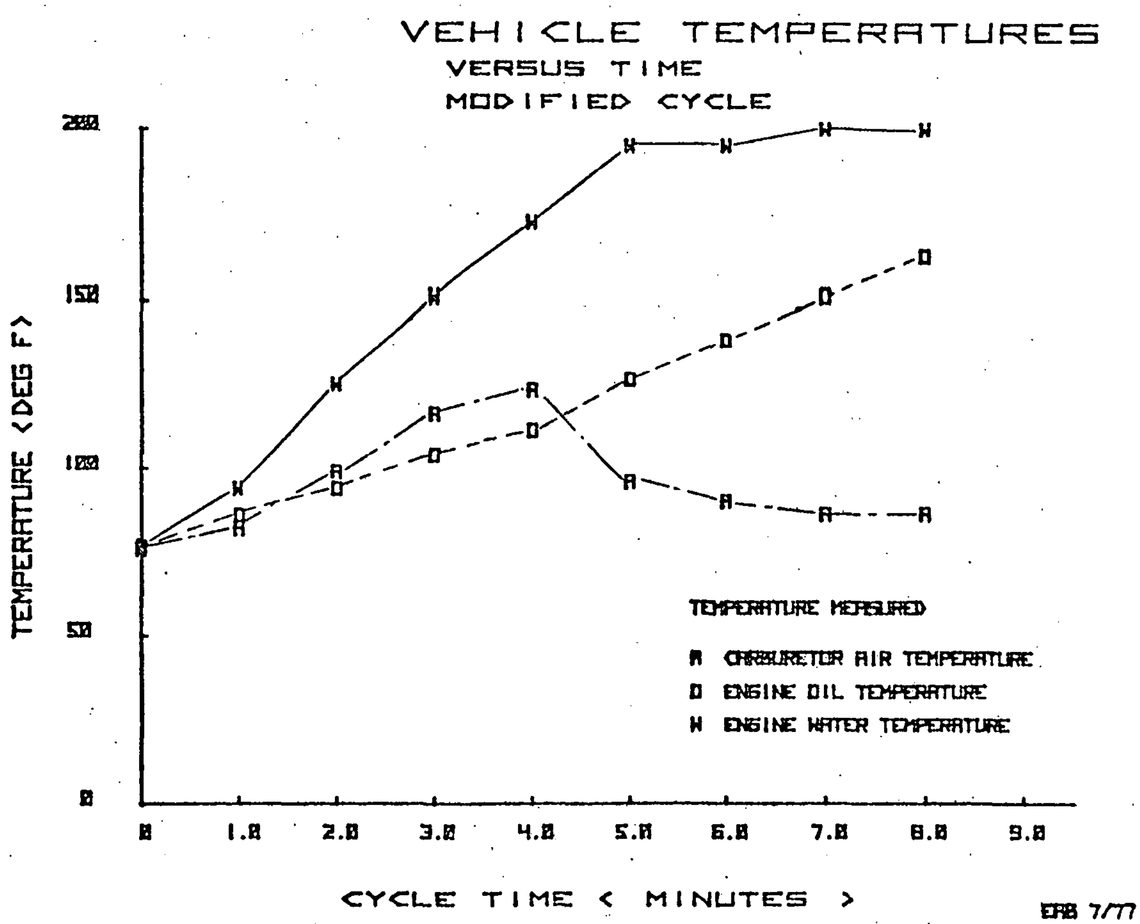


Figure 10

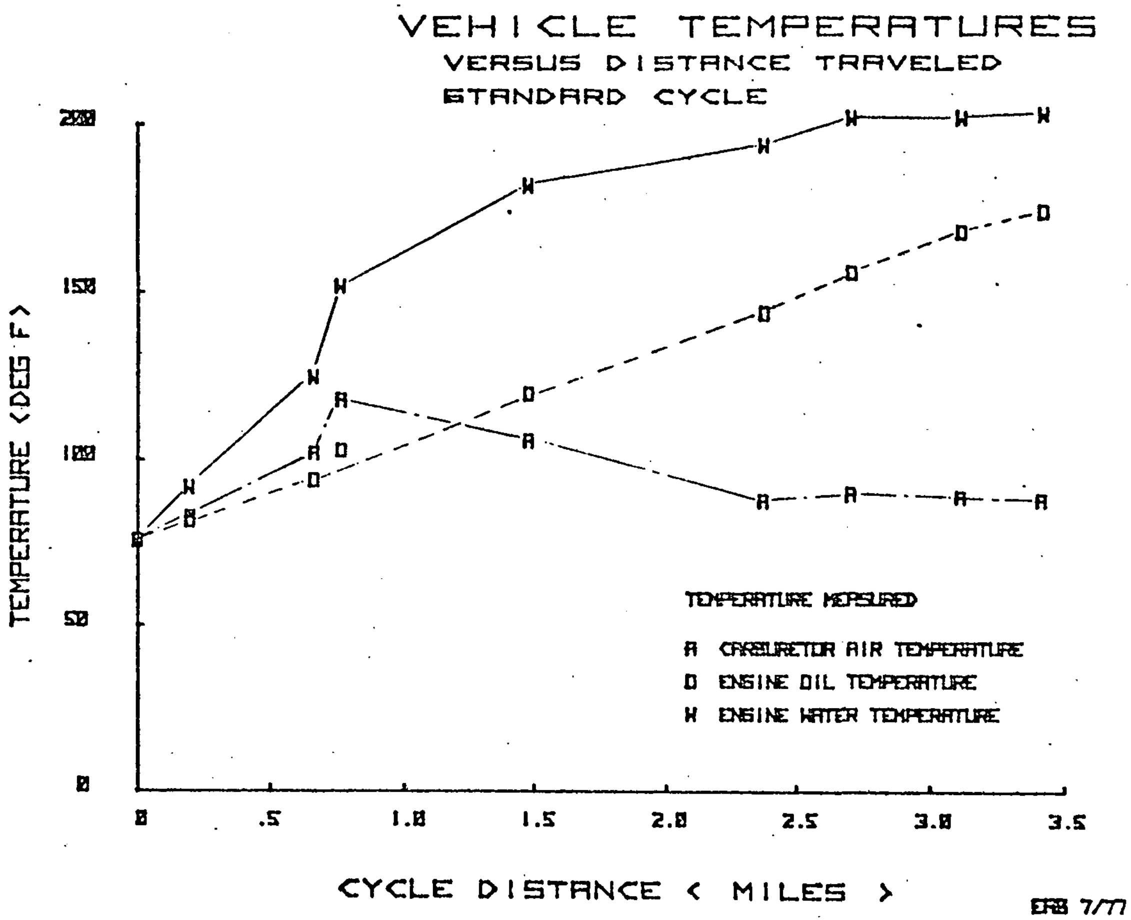


Figure 11

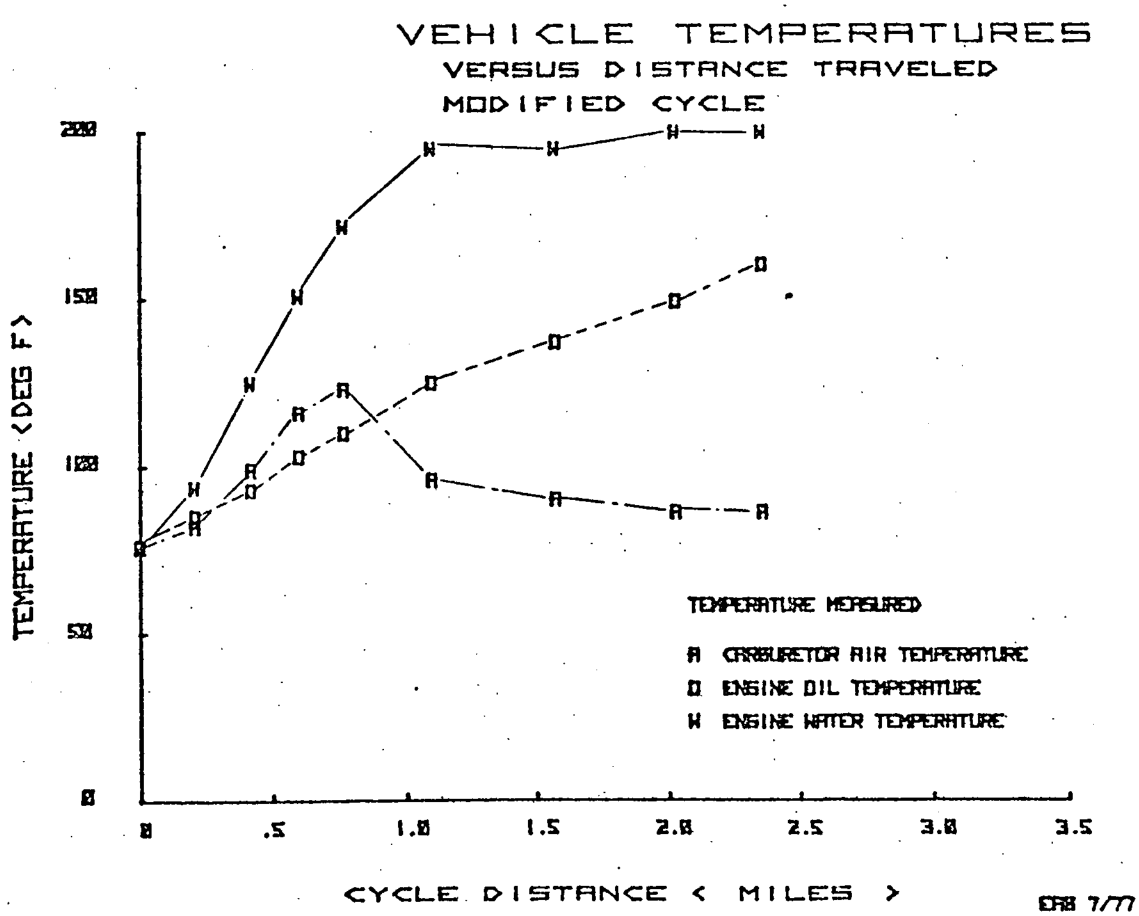


Figure 12

Vehicle Temperature Summary

Parameter	Standard Cycle	Modified Cycle
Carburetor air temperature		
a) Peak temperature and time into cycle	124°F @ 210 sec.	123°F @ 240 sec.
b) Stabilize temperature and time into cycle	89°F @ 285 sec.	86°F @ 345 sec.
Engine water temperature	202°F @ 270 sec.	201°F @ 300 sec.
Engine oil temperature	216°F @ 21 min.	220°F @ 20 min.
Catalyst skin temperature	620°F @ 300 sec.	560°F @ 420 sec.

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1976 Chevrolet Impala
Emission control system - EGR, Catalyst

Engine

type	4 stroke, Otto cycle, OHV, V-8
bore x stroke	4.00 x 3.48 in (101.6 x 88.4 mm)
displacement	350 cu in. (5735 cc)
compression ratio	8.5:1
maximum power @ rpm	
fuel metering	Single 2 barrel carburetor
fuel requirement	Regular unleaded (tested with 96 RON Indolene unleaded, containing .03 percent sulfur)

Drive Train

transmission type	Automatic
final drive ratio	2.73

Chassis

type	Front engine, rear drive
tire size	HR 78 x 15
curb weight	4266 pounds
inertia weight	4500 pounds
passenger capacity	6

Emission Control System

basic type	Exhaust Gas Recirculation (EGR) Singel Pelletted Catalyst Early Fuel Evaporative System (EFE)

Durability accumulated on system - 5100 miles

Vehicle Identification Number - 1L47V61234368

Table 1
'75 FTP Mass Emissions
grams per mile

Test	Bag 1 Cold Transient					Bag 2 Hot Transient									
Number	HC	CO	CO_2	NOx	MPG	HC	CO	CO_2	NOx	MPG	HC	CO	CO_2	NOx	MPG
78-0451*	1.58	27.32	688	3.28	12.1	.14	1.53	733	1.92	12.1	.25	4.19	617	2.91	14.2
78-0559*	1.49	27.86	632	2.66	13.0	.13	0.18(1)	665	1.70	13.3	.42	4.52	565	2.49	15.5
78-0484**	2.31	48.01	716	1.51	11.1	.22	4.36	690	2.70	12.7	.22	1.47	637	1.52	13.9
78-0485**	2.28	38.34	743	1.75	10.9	.23	4.53	727	3.03	12.1	.41	1.49	659	1.60	13.4

* Baseline standard cycle.
** Modified cycle.

(1) Although this value is exceptionally low for CO for this vehicle, for this test, identical results were achieved for bag 2 CO for both the modal and CVS systems. These systems sample and analyze the pollutants independently.

Table 2
'75 FTP Composite Mass Emissions
grams per mile

Test Number	HC	CO	CO_2	NOx	MPG
78-0451*	0.47	7.56	692	2.47	12.6
78-0559*	0.49	7.06	631	2.11	13.8
78-0484**	0.54	10.54	683	2.27	12.7
78-0485**	0.58	9.15	715	2.54	12.1

* Baseline standard cycle.
** Modified cycle.

Table 3
'74 FTP Composite Mass Emissions
grams per mile

	Cold Start					Hot Start				
Test Number	HC	CO	CO_2	NOx	MPG	HC	CO	CO_2	NOx	MPG
78-0451	.84	13.97	716.41	2.59	12.1	.20	2.82	682	2.41	12.9
78-0559	.79	13.52	654.9	2.17	13.8	.29	2.27	622	2.09	14.2
78-0484**	.97	20.11	700	2.27	12.1	.22	3.32	671	2.28	13.1
78-0485**	.97	16.74	732	2.57	11.6	.29	3.43	702	2.52	12.5

** Modified cycle.

Vehicle Temperature Summary

Parameter	Standard Cycle	Modified Cycle
Carburetor air temperature		
a) Peak temperature and time into cycle	124°F @ 210 sec.	123°F @ 240 sec.
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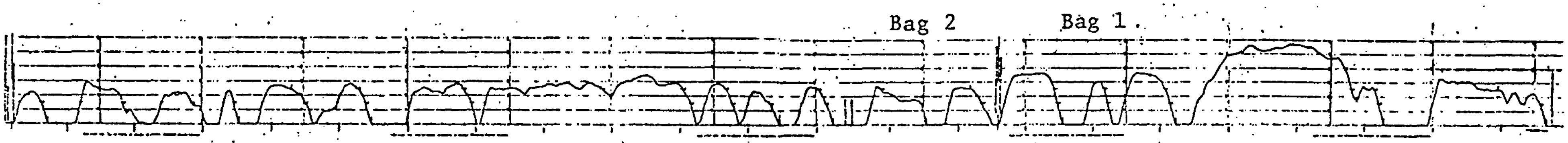
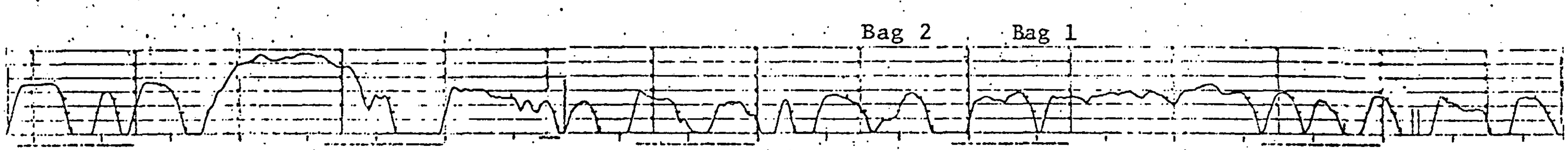


Standard Cycle



Modified Cycle

Figure 12
Driving Cycles