77-14 CH

Test Results of a Dodge Dart Equipped with the Holley Sonic Carburetor

December 1977

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

Abstract

Under EPA contract, the Holley Carburetor Division of Colt Industries developed an application of the Dresser sonic carburetor design for evaluation by EPA. The Holley sonic carburetor was tested for emissions and fuel economy in a 1975 California model Dodge Dart with a 3.7 litre (225 cu in.) six cylinder engine. The test results were compared to those of the same vehicle in baseline condition (production carburetor and emission control system).

Factors such as the air/fuel ratio, idle enrichment, and air injection were varied to optimize the emissions. After an optimum setting was found, the emissions were still generally higher than the same vehicle in baseline condition. Addition of a three-way catalyst reduced NOx below baseline, but HC, fuel economy and especially CO values were still greater than baseline.

Conclusions

1) There were no configurations tested for which the sonic carbureted vehicle was able to achieve emissions and fuel economy results comparable to the same vehicle in production configuration.

2) The sonic carburetor operating in conjunction with the other emission control devices, including the oxidation catalyst, was able to maintain emission levels within the 1977 Federal Standards.

3) '75 FTP results with the three-way catalyst installed (CO 15-30 g/mi; NOx 0.2-0.5 g/mi; fuel economy 14.5-16 mpg) as well as very low emission levels in steady state tests (Tables 2, 4, 5) indicate the following problem areas:

A) The time averaged mixture entering the engine during a non-steady state driving cycle may be much richer than indicated by the air/fuel trim setting alone. This could be caused by the vacuum actuated power enrichment system as well as the accelerator pump operation.

B) During non-sonic operation (low manifold vacuum) the air/fuel ratio becomes more variable and the fuel distribution less uniform. These conditions are due to varying air velocity through the carburetor venturi and lack of a sonic shock wave to break up the fuel droplets.

C) The EGR rate appears to be much greater than necessary for operation with the three-way catalyst.

These factors are all aggravated by high load operation, which occurs often due to the low power/weight ratio of this vehicle.

4) Driveability of the test vehicle with the sonic carburetor was considered to be poor. Holley's test of the vehicle in baseline condition indicated that it also had poor driveability. The sonic carburetor cannot, therefore, be considered to be the source of the driveability problem. Additionally, it should be noted that the sonic carburetor did not improve driveability.

5) This test program covered a wide range of carburetor/emission control configurations, but a program of much larger scope would be necessary to determine with certainty the maximum capabilities and specific weaknesses of the sonic carburetor.

Background

EPA's Emission Control Technology Division is interested in evaluating systems which offer potential for emissions reduction or improvement in fuel economy compared to conventional engines and vehicles because of the obvious benefits to the Nation from the identification of such systems. In those cases in which review by EPA technical staff suggests that the data available show promise for a new system, tests are performed at the EPA Motor Vehicle Emission Laboratory at Ann Arbor, Michigan. The results of all such tests are set forth in a series of Technology Assessment and Evaluation Reports, of which this report is one.

Induction systems are one of the focal points in the search for better fuel economy and lower emissions. This is because precise control of the inlet mixture allows greater control of the exhaust emissions as well as improved fuel economy.

The subject of this report is a carburetor concept developed by Dresser Industries and patented as the Dresserator Inductor. EPA wished to evaluate this concept because of (1) its claimed ability to provide a constant, homogeneous air/fuel mixture over a wide range of engine operating conditions and (2) its demonstrated capability on Dresser prototypes (TAEB test report 75-7AW). Holley Carburetor Division of Colt Industries was awarded a contract by EPA to develop a complete vehicle/carburetor/ emission control package based on Dresser's design. For a test vehicle, Holley chose a 1975 Dodge Dart with a six cylinder engine and California emission controls. Holley then built a sonic carburetor specifically for use on the test vehicle, while also modifying the EGR system to be compatible with the new carburetor. All other engine calibrations, including the ignition system and valve timing, were left in baseline condition.

After Holley completed development and testing of the modified vehicle, it was sent to the EPA for the testing described in this report.

System Description

The test vehicle was a 1975 Dodge Dart powered by a 3.7 litre (225 cu in.) six cylinder engine with an automatic transmission. The vehicle was calibrated to California specifications, so the emission control system consisted of an air pump, EGR, and oxidation catalyst. Preliminary testing with the sonic carburetor retained these components, although the EGR had been modified to be back pressure controlled. Subsequent tests were conducted with other configurations as described in the test procedures.

The following is a description of the sonic carburetor from the Holley report:

> "Functionally, this carburetor is shown in block diagram form in Figure 2.* The following work description will help clarify the functions.
>
> The air section is based on the Dresser Industries Model III variable area venturi. The venturi throat is rectangular in cross-section with one dimension of the throat fixed and the other variable with throttle position. The movable surface and the side opposite are essentially flat surfaces. A contoured shape is designed into the remaining two surfaces to form a venturi. In this design, there is a constant ratio of throat area to inlet area over the complete operating range.
>
> The fuel metering and distribution bar, located upstream of the venturi throat, has tapered fuel metering slots that also aid fuel distribution and fuel atomization in the venturi air section. The fuel bar is attached to the movable venturi section such that travel of the fuel bar is identical to the travel of the movable venturi section. The fuel slots are tapered in the fuel bar such that the fuel metering area is proportional to the venturi throat area.
>
> The air velocity at the venturi throat is sonic for all inlet manifold vacuum pressures** in excess of approximately five inches of mercury.
>
> The variable area entrance to the venturi is designed such that the velocity at any point in the entrance is a fixed percentage of the velocity at the venturi throat. The fuel bar is located a fixed distance upstream of the venturi throat to give ample velocity over the fuel bar to provide good distribution and small fuel particle size. Further reduction in fuel particle size occurs as the mixture of air and fuel passes through the shock waves associated with supersonic and subsonic velocities as they occur in the diffuser section of the venturi.

* and in schematic form in Figure 1
** depressions

The total pressure differential that is available for fuel metering is the differential from the float bowl to the venturi vacuum at the fuel bar. An airflow bleed network is used with both fixed and variable restrictions to use the correct percentage of this available pressure differential for fuel metering.

Cold enrichment is achieved through the use of a carburetor electric choke mechanism to control the fuel metering pressure differential as a percentage of the total available pressure differential. This cold enrichment fuel/air ratio is thus metered as a function of engine compartment temperature (sensed in the air cleaner, after the filter) and time from engine start.

The cold crank fuel is supplied when the engine is cold during crank cycle only. Also, to avoid fuel flooding, the crank fuel can be shut off during the cold crank by selecting wide-open throttle position.

A conventional carburetor acceleration fuel pump delivers fuel in proportion to a change in throttle position. This fuel is injected into the airstream ahead of the fuel bar.

Power enrichment is achieved by sensing manifold vacuum and increasing the fuel/air ratio for low manifold vacuum. This is accomplished by increasing the fuel metering pressure differential from the normal part throttle metering level as a function of manifold vacuum. Power enrichment also occurs near wide-open throttle by the contour on the fuel bar."

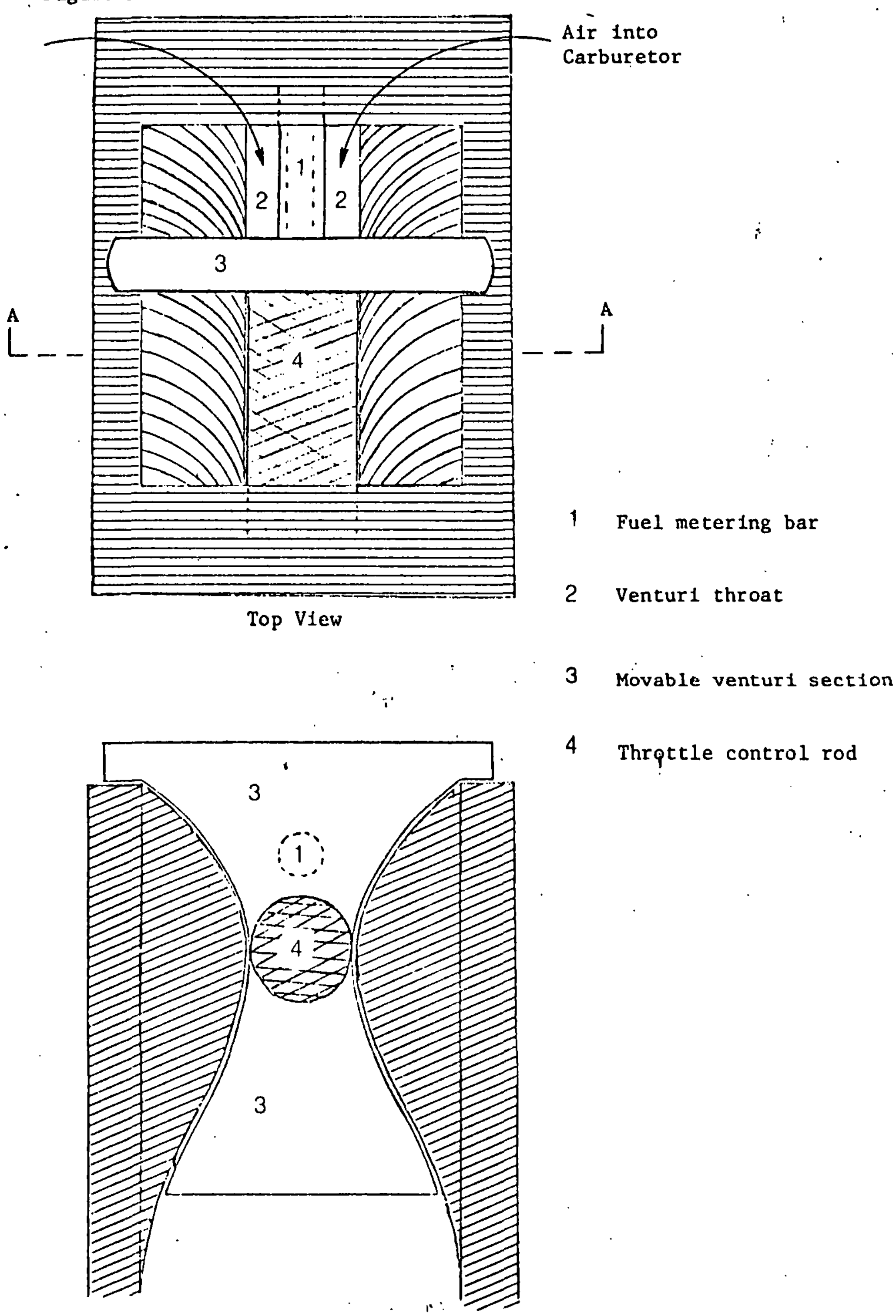
Test Program

Exhaust emissions and fuel economy tests were conducted in accordance with the 1975 Federal Test Procedure ('75 FTP), the EPA Highway Fuel Economy Test (HFET), and steady state tests. Evaporative emissions were not measured.

Numerous tests were conducted with various emission control systems and air/fuel ratios. The basic mixture is adjusted with a trim setting screw, such that turning out (opening) the trim setting screw increases the air/fuel ratio. The mixtures tested are referred to in terms of the number of turns open (T.O.) of the trim setting screw. The air/fuel ratios corresponding to the various trim settings are shown in Figure 3.

For tests run with the secondary air disconnected, the output hose from the air pump was disconnected at the pump, and the hose was plugged. For all '75 FTP's with EGR, the activation of the EGR was delayed until 70 seconds after the start of the test.

Figure 1 - Sonic Carburetor Schematic



Section A-A

FIGURE 2

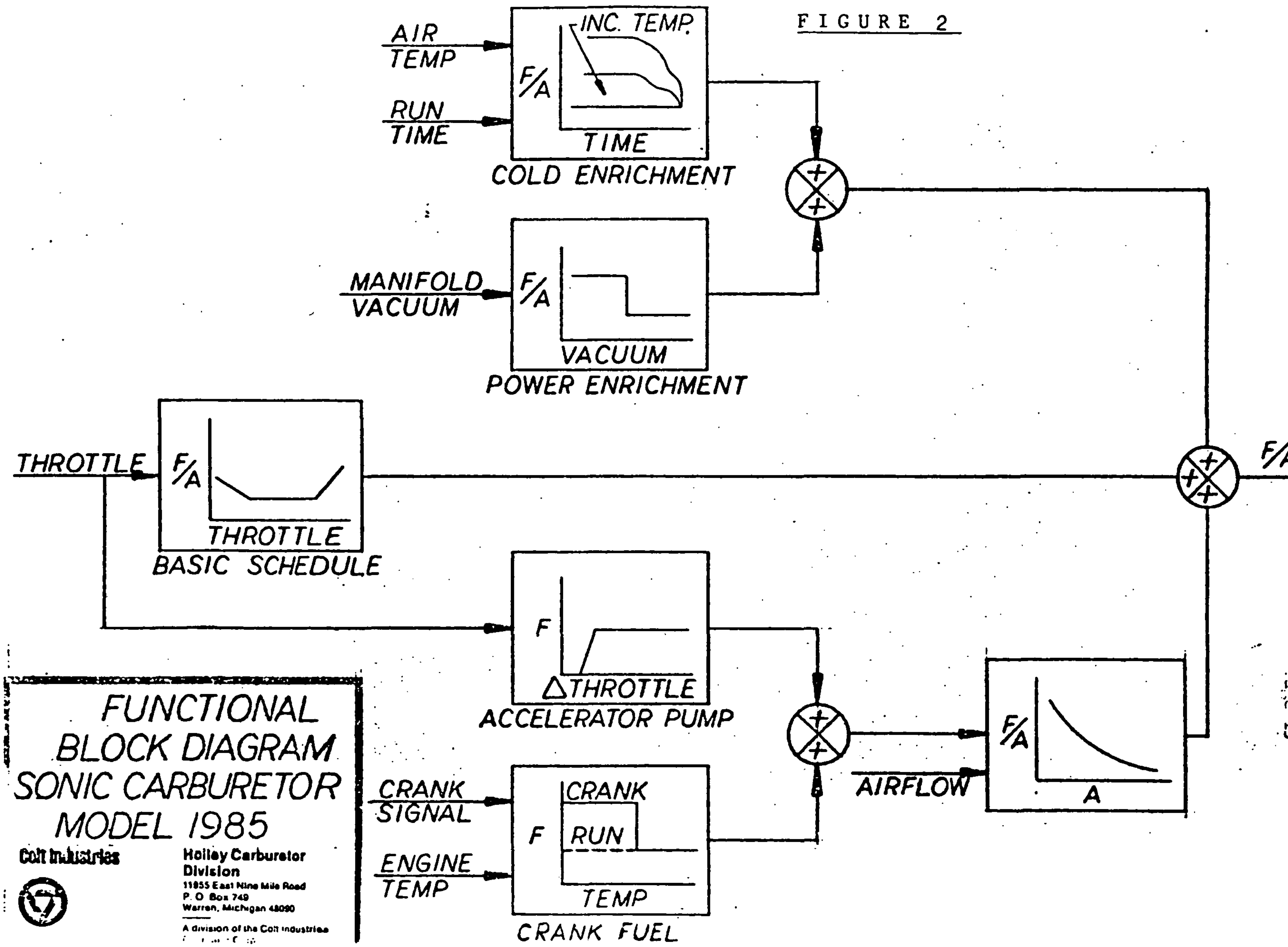
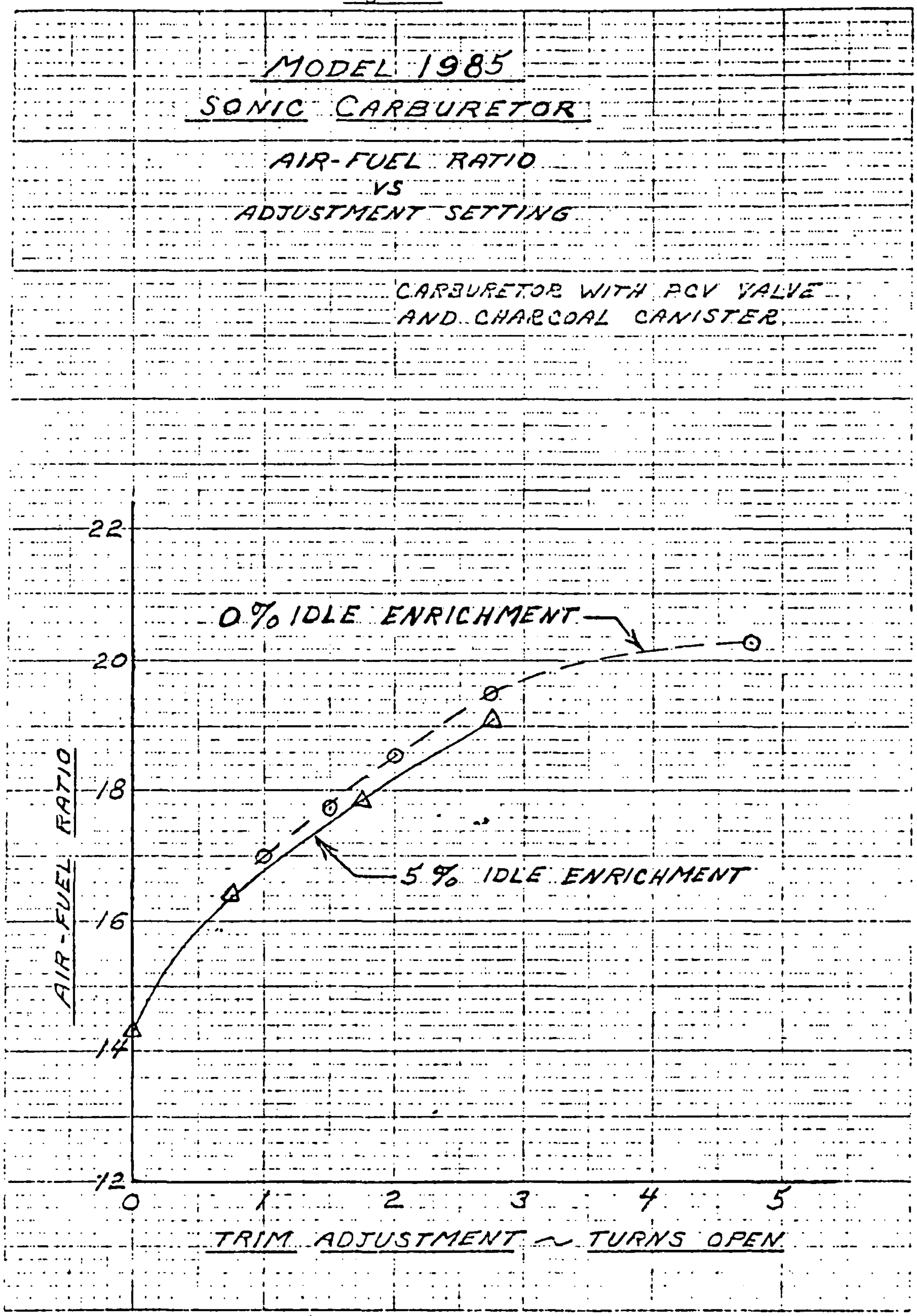

AIR TEMP
RUN TIME
F/A
INC. TEMP.
TIME
COLD ENRICHMENT
MANIFOLD VACUUM
F/A
VACUUM
POWER ENRICHMENT
THROTTLE
F/A
THROTTLE
BASIC SCHEDULE
F/A
F
Δ THROTTLE
ACCELERATOR PUMP
AIRFLOW
F/A
A
CRANK SIGNAL
ENGINE TEMP
F
CRANK
RUN
TEMP
CRANK FUEL
FUNCTIONAL BLOCK DIAGRAM SONIC CARBURETOR MODEL 1985
Colt Industries
Holley Carburetor Division
11955 East Nine Mile Road
P. O. Box 749
Warren, Michigan 48090
A division of the Colt Industries

Figure 3



MODEL 1985
SONIC CARBURETOR
AIR-FUEL RATIO
VS
ADJUSTMENT SETTING
CARBURETOR WITH PCV VALVE
AND CHARCOAL CANISTER
0% IDLE ENRICHMENT
5% IDLE ENRICHMENT
AIR-FUEL RATIO
22
20
18
16
14
12
0
1
2
3
4
5
TRIM ADJUSTMENT ~ TURNS OPEN

The following tests were conducted:

I. Oxidation Catalyst Installed, with EGR

A. 5% Idle Enrichment, Secondary Air Disconnected

# of Tests	2 3/4 Turns Open (T.O.)
7	'75 FTP (EGR after 70 sec.)
7	HFET
2	sets of Steady States

B. 0% Idle Enrichment

1. Secondary Air Connected

9 '75 FTP @ 0-2 T.O. (EGR after 70 sec.)

4 HFET @ 0-2 T.O.

4 sets of Steady States @ 0-2 1/4 T.O.

2. Secondary Air Disconnected

4 '75 FTP @ 0-3 T.O. (EGR after 70 sec.)

1 HFET @ 3 T.O.

1 set of Steady States @ 3 T.O.

II. Three-Way Catalyst Installed, Sec. Air Disconnected, 0% Idle Enrichment

A. With EGR

14 '75 FTP (EGR after 70 sec.) @ 0-3 1/2 T.O.

4 HFET @ 1 T.O.

1 set of Steady States @ 35 mph, 0-1/2 T.O.

1 set of Steady States @ 1 T.O.

B. Without EGR

1 '75 FTP @ 1 T.O.

4 Hot Start LA-4 @ 1 1/2-3 T.O.

Test Results - Emissions

The results of the '75 FTP testing with the oxidation catalyst installed are shown in Figure 4 and Table 1. For air/fuel trim adjustments leaner than 1/2 turn open the emission levels are within the 1977 federal standards while yielding city fuel economies of 15-16 liters/100 km (15-16 mpg).

The effect of disconnecting the secondary air at very lean mixtures is a slight increase in HC and CO emissions coupled with a similar decrease in NOx. The data for the test with the air/fuel trim adjustment zero turns open with the secondary air disconnected is not included in Figure 4 due to its extremely high CO value. This indicates that secondary air is essential to clean operation in the richer ranges tested.

When the oxidation catalyst was replaced with a 3-way catalyst, a series of tests at 35 mph was run with the modal analyzer. The results are shown in Figure 5 and Table 2. The significant aspect of these results is the narrow "window" of air/fuel ratios (near 1/3 turn open) for which the 3-way catalyst is effective.

The next series of '75 FTPs was run at trim settings somewhat leaner than 1/3 turn open in an attempt to compensate for the enrichment supplied during the acceleration portions of the test cycle. Figure 6 and Table 3 show that relative to the oxidation catalyst the 3-way catalyst substantially reduced NOx emissions, while HC emissions increased slightly, and CO emissions increased drastically to over 20 g/mi (12 g/km). The fact that the emission control capability demonstrated in the steady state testing (Tables 2, 4, 5) was not reflected in the FTP data indicates that the air/fuel ratio was not held stable during the numerous transients of the FTP.

To get a better idea of what was occurring, the FTP emissions were analyzed by mode for acceleration, cruise, and deceleration. Figures 7 through 11 show that the major problem areas for both HC and CO were the acceleration portions of the test cycle. This can be attributed to the enrichment of the mixture by the accelerator pump and power enrichment system to a point outside the effective operating "window" of the 3-way catalyst. This meant that an even leaner range needed investigation.

To investigate emissions in a leaner mixture range a series of hot start LA-4's was conducted without EGR at air/fuel trim adjustments ranging from 1.5 to 3 turns open. Although the hot LA-4 emissions results cannot be compared directly to the '75 FTP emissions, both procedures would show similar trends. Figure 12 shows that there is no significant variation of emissions in the trim adjustment range of 1.5 to 3 turns open. The lack of EGR in these tests resulted in relatively high NOx emission levels with low HC and CO levels. Therefore, '75 FTP's were conducted with EGR at trim adjustments of 2 1/2 and 3 1/2 turns open. This configuration reduced NOx emission substantially, but CO emissions returned to over 15 g/mi (9.3 g/km).

During the '75 FTP, emission samples are collected in three bags - cold transient, cold stabilized, and hot transient. Emissions during the cold transient phase (bag 1) are affected by warm-up time of the catalyst and operation of the carburetor cold enrichment system. The percentage of composite '75 FTP emissions contributed by bag 1 (see Table 8) indicates the effect of these factors on emissions. With the oxidation catalyst a large percentage of total HC and CO emissions comes from bag 1, but with the three-way catalyst these percentages are much smaller. It should be noted that the actual bag 1 mass emissions depend on the total composite emissions as well as the bag 1 percentages.

Fuel Economy

Results for the highway fuel economy tests appear in Table 6. The results ranged from 22.1 mpg to 25.4 mpg, where the highest values were achieved with the 3-way catalyst. This is slightly below the 26.0 mpg that the baseline vehicle averaged after 4000 miles durability accumulation.

Driveability

No quantitative driveability tests were conducted, but the following observations were noted:

(1) All cold starts-(all '75 FTPs) required at least three pumps of the accelerator pedal.

(2) All cold starts were accompanied by at least one backfire through the carburetor and usually a stall.

(3) Drivers considered the vehicle seriously underpowered. Acceleration times for 0-60 mph ranged from twenty to twenty-five seconds.

Comparison With Baseline

The sonic carburetor operating in conjunction with other emission control devices was able to maintain emissions within the 1977 Federal Standards. However, this test program was conducted to evaluate the relative merits of the sonic carburetor versus the production carburetor. Test results supplied by Holley for the baseline vehicle with production carburetor (Holley model 1945) appear in Table 7.

Hydrocarbon emissions of the test vehicle remained comparable to the production vehicle. The minimum average CO value for a given test vehicle configuration was over 5 g/mi (3 g/km) compared to 2.3 g/mi (1.5 g/km) for the production vehicle. Excluding tests with CO levels above current standards, minimum NOx emission levels were approximately 1.1 g/mi (0.7 g/km) compared to 0.9 g/mi (0.6 g/km) for the production vehicle. The test calibration which yielded the best highway fuel economy while meeting the 1977 federal emission standards consisted of setting the air/fuel trim adjustment two turns open and using the oxidation catalyst. This maximum fuel economy was 24.1 mi/gal (9.8 L/100 km), which is slightly less than the 26.0 mi/gal (9.0 L/100 km) of the production vehicle. Driveability of the test vehicle was poor, but that of the same vehicle in baseline condition was also poor.

In summary, there were no configurations tested for which the sonic carbureted vehicle was able to achieve emissions and fuel economy results comparable to the production vehicle.

Applicability of Results

The conclusions drawn from this EPA evaluation test are valid only for the specific test vehicle used. A complete evaluation of the effectiveness of any system in achieving improvements on various types of vehicles requires a much larger sample of test vehicles than is feasible in the evaluation projects conducted by EPA. Test results for one vehicle serve only as an indication of results likely to be obtained in the testing of another vehicle of similar specification.

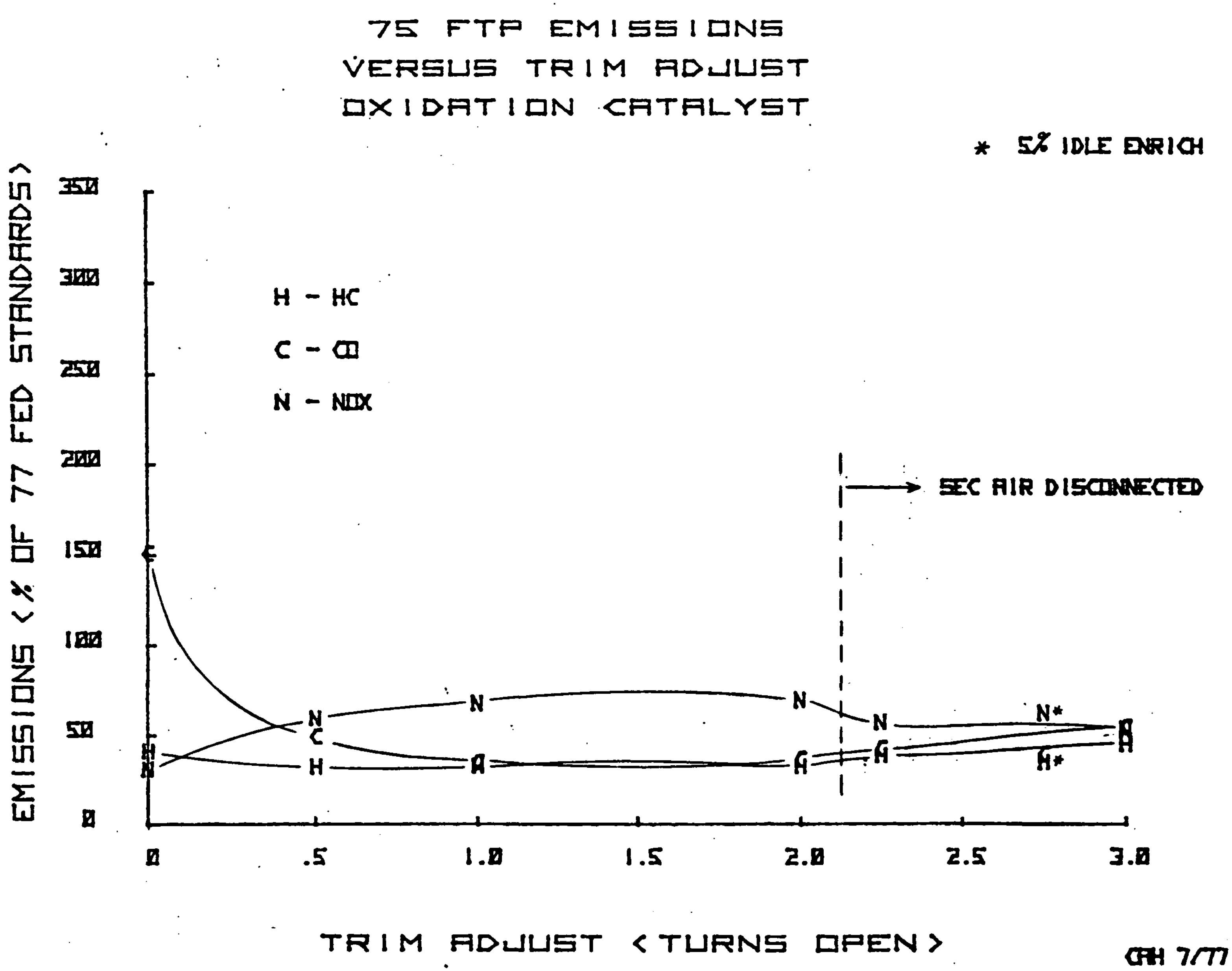

75 FTP EMISSIONS
VERSUS TRIM ADJUST
OXIDATION CATALYST
* 5% IDLE ENRICH
EMISSIONS (% OF 77 FED STANDARDS)
350
300
250
200
150
100
50
0
H - HC
C - CO
N - NOX
SEC AIR DISCONNECTED
0
.5
1.0
1.5
2.0
2.5
3.0
TRIM ADJUST (TURNS OPEN)
CAH 7/77

Figure 4

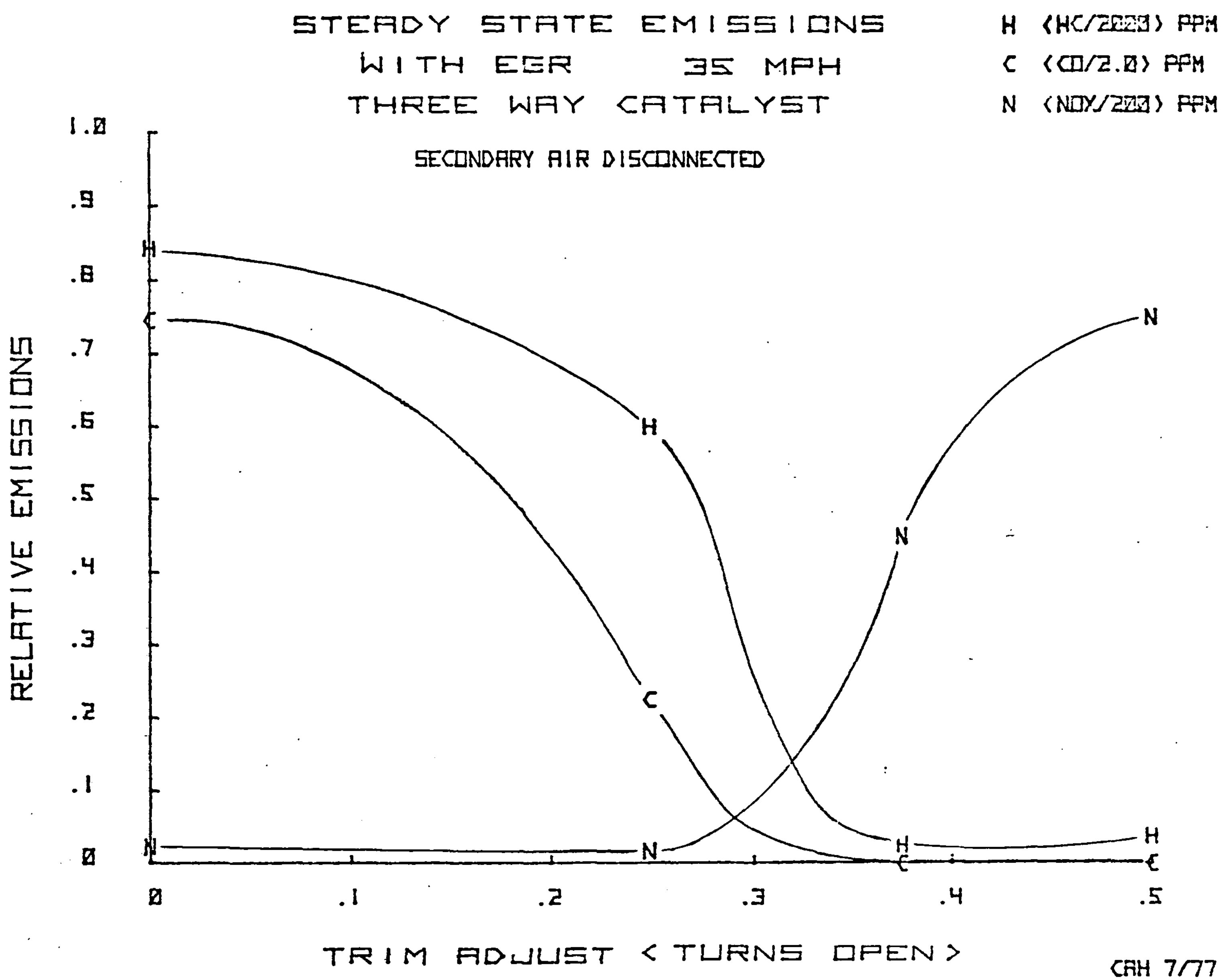

STEADY STATE EMISSIONS
WITH EGR 35 MPH
THREE WAY CATALYST
H (HC/2000) PPM
C (CO/2.0) PPM
N (NOX/200) PPM
SECONDARY AIR DISCONNECTED
RELATIVE EMISSIONS
1.Ø
.9
.8
.7
.6
.5
.4
.3
.2
.1
Ø
.1
.2
.3
.4
.5
TRIM ADJUST <TURNS OPEN>
CAH 7/77

Figure 5

75 FTP EMISSIONS
VERSUS TRIM ADJUST
THREE WAY CATALYST

SEC AIR DISCONNECTED

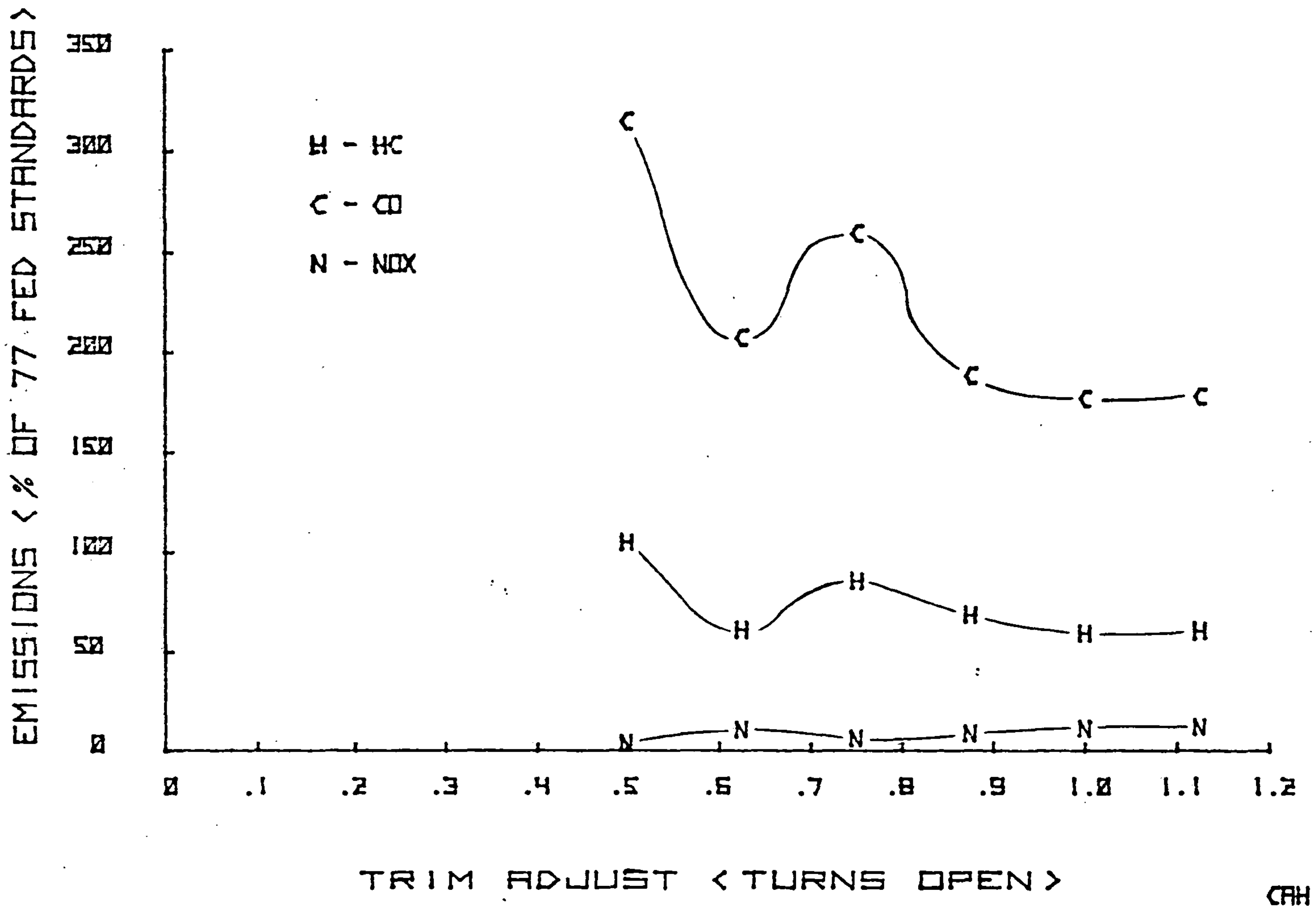


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Figure 6

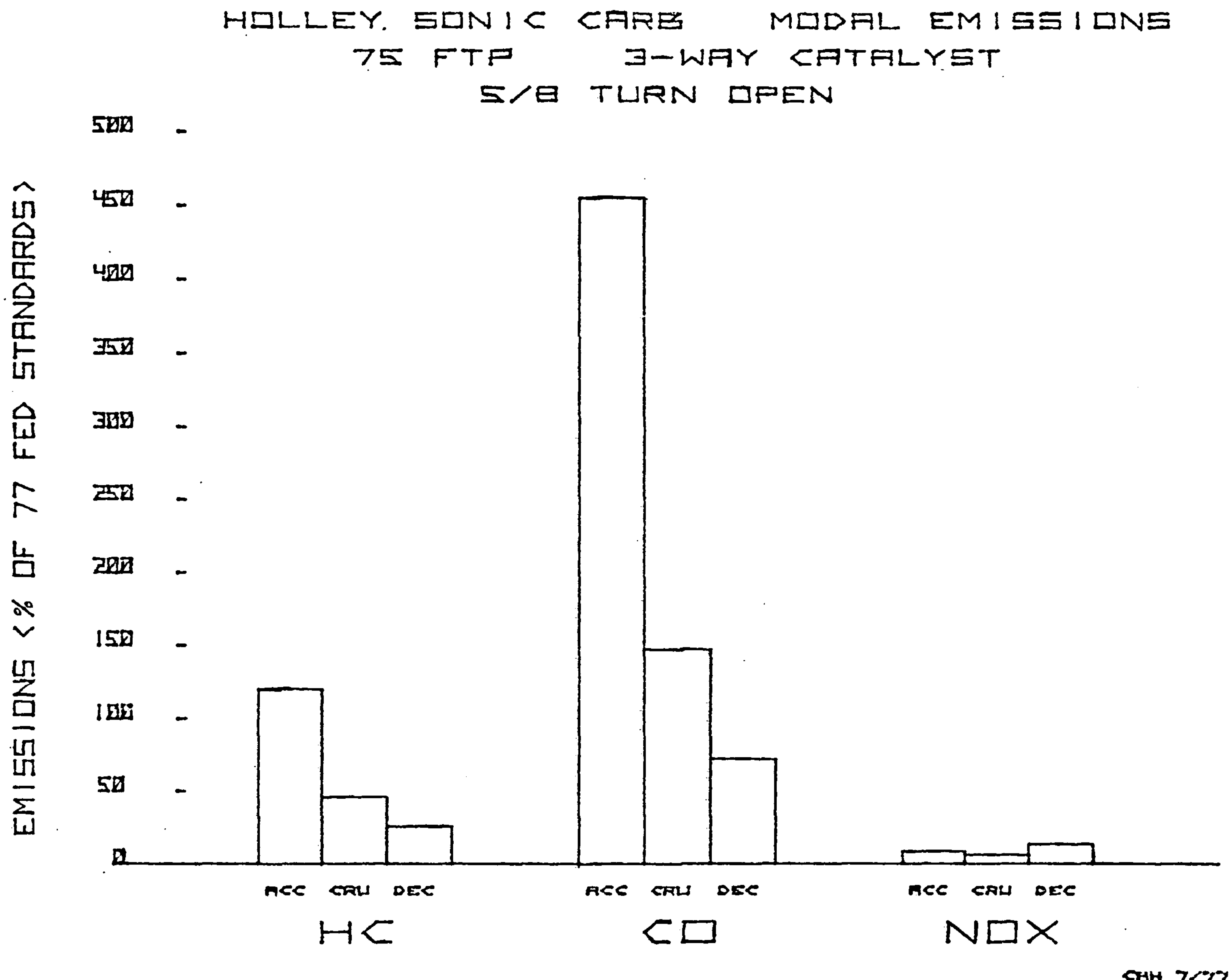

HOLLEY SONIC CARB MODAL EMISSIONS
75 FTP 3-WAY CATALYST
5/8 TURN OPEN
EMISSIONS (% OF 77 FED STANDARDS)
500
450
400
350
300
250
200
150
100
50
0
ACC CRU DEC
ACC CRU DEC
ACC CRU DEC
HC
CO
NOX
CHH 7/77

Figure 7

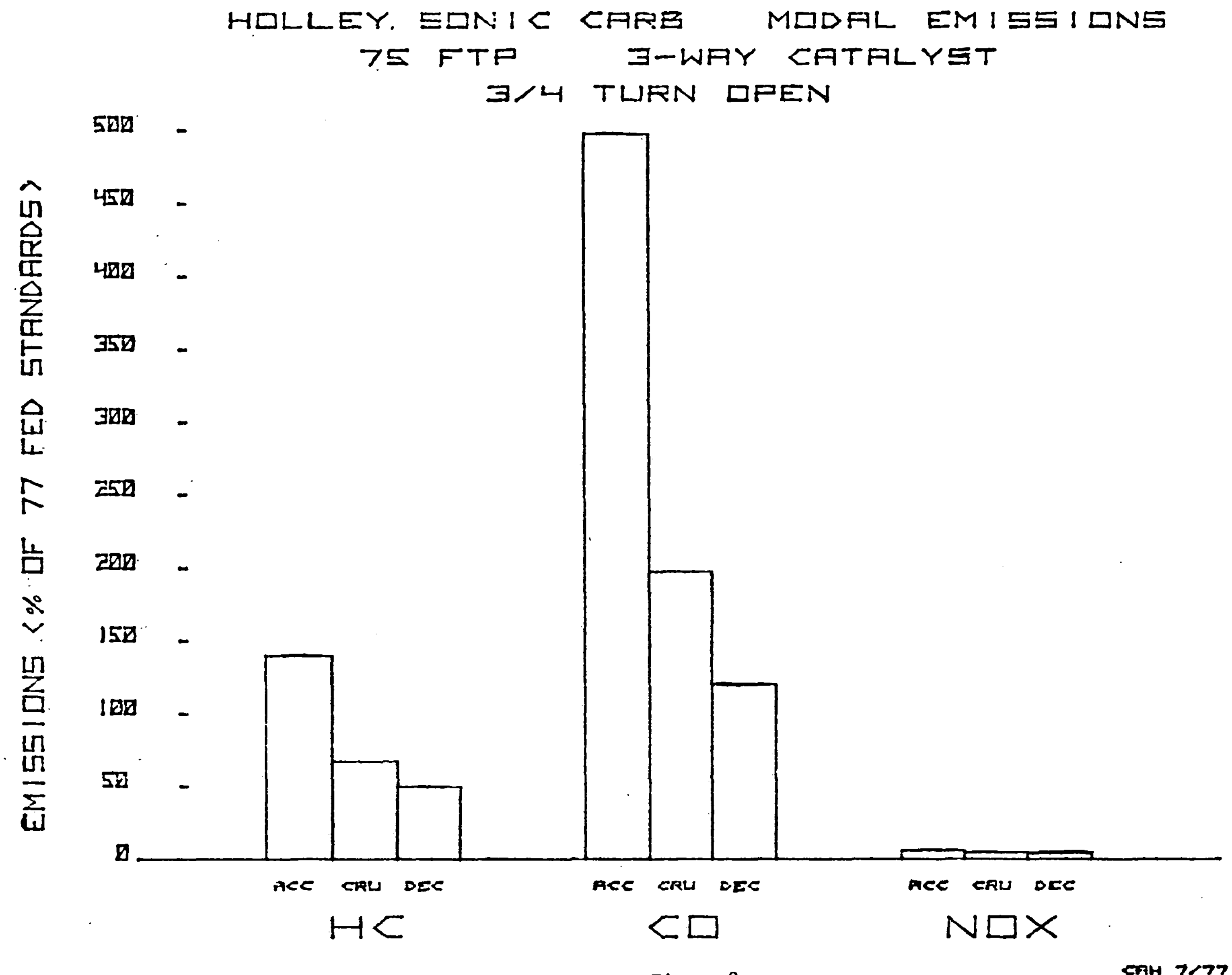

HOLLEY SONIC CARB MODAL EMISSIONS
75 FTP 3-WAY CATALYST
3/4 TURN OPEN
EMISSIONS (% OF 77 FED STANDARDS)
500
450
400
350
300
250
200
150
100
50
0
ACC CRU DEC
HC
ACC CRU DEC
CO
ACC CRU DEC
NOX
CAH 7/77

Figure 8

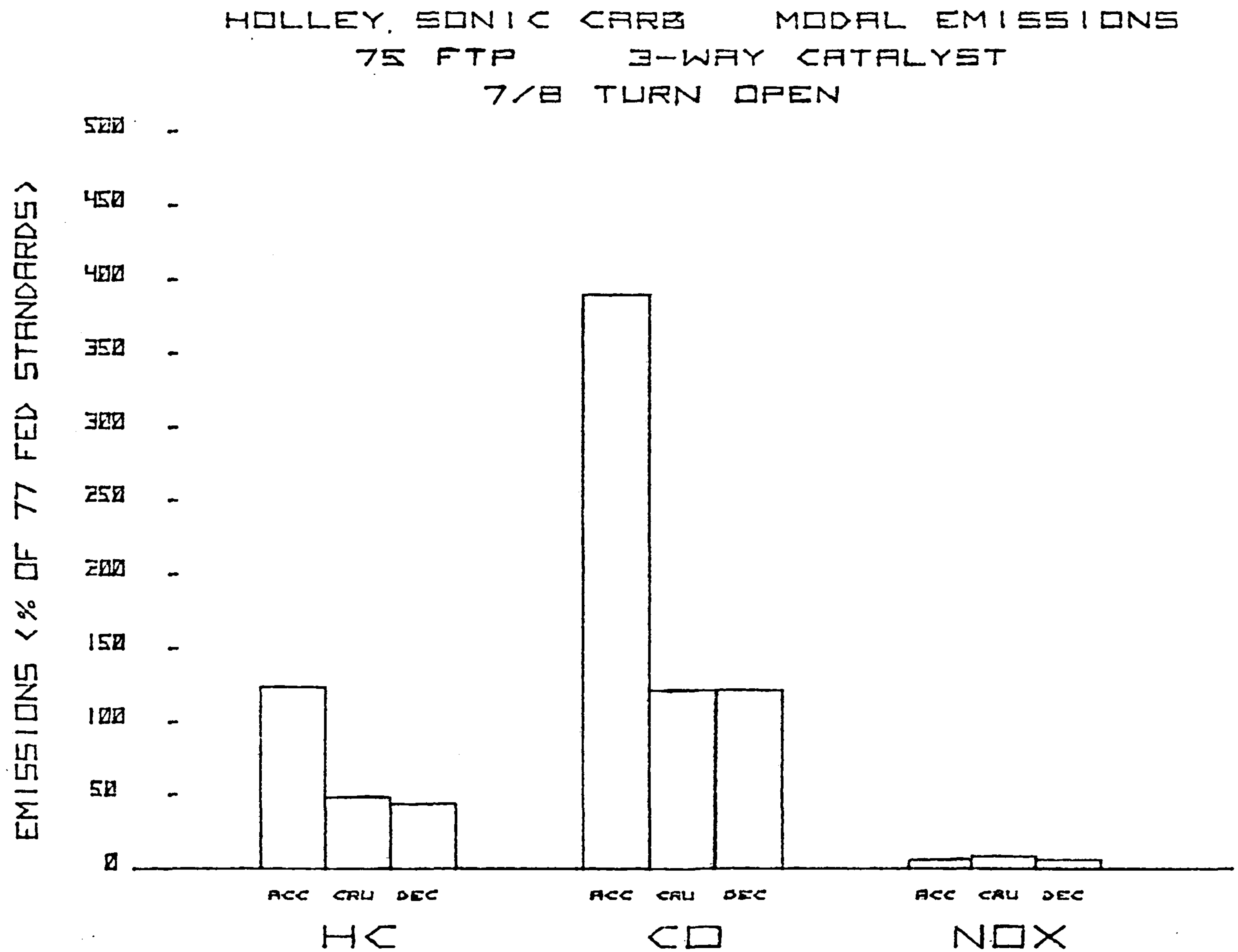


Figure 9

CRH 7/77

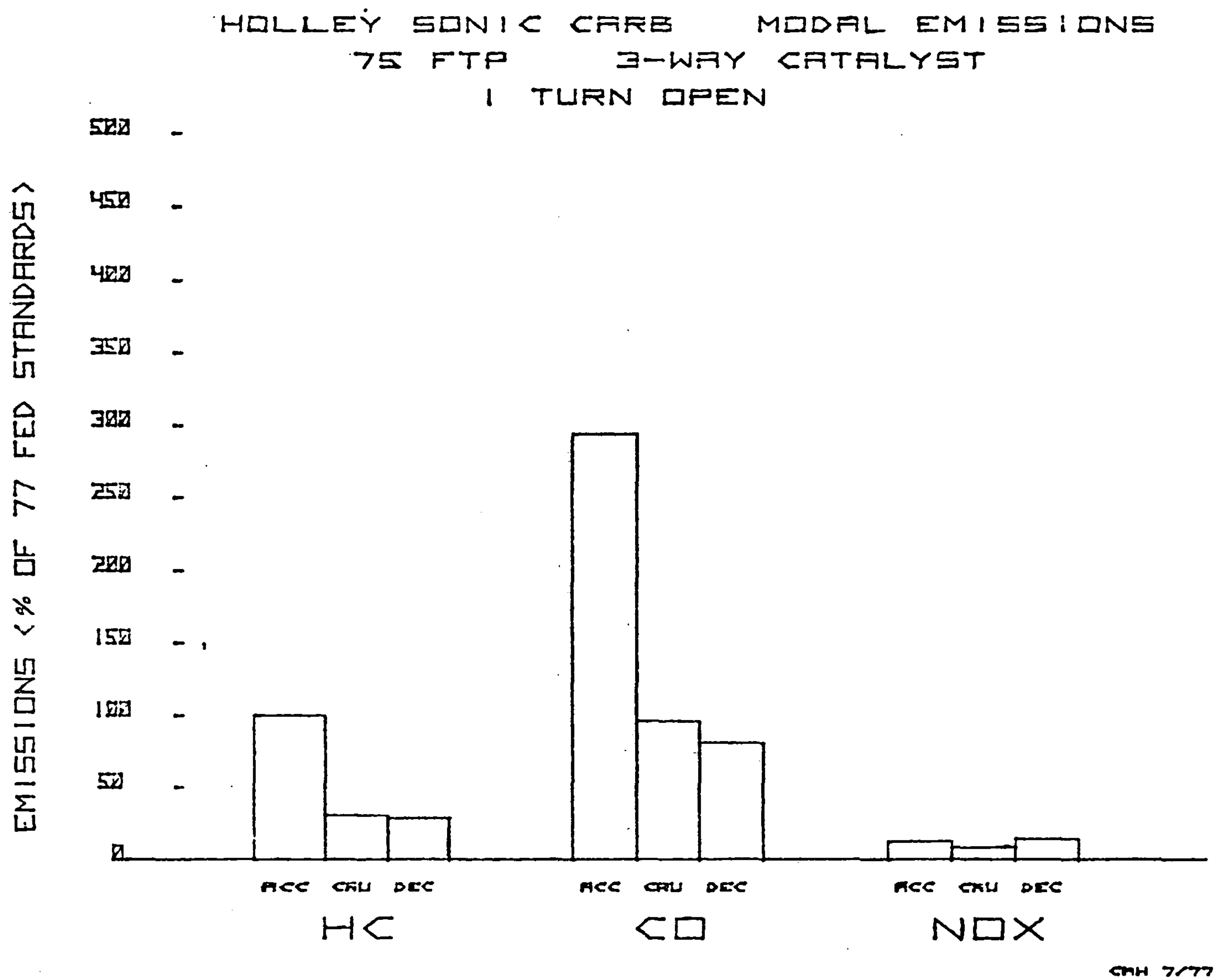

HOLLEY SONIC CARB MODAL EMISSIONS
75 FTP 3-WAY CATALYST
1 TURN OPEN
EMISSIONS (% OF 77 FED STANDARDS)
500
450
400
350
300
250
200
150
100
50
0
ACC CRU DEC
ACC CRU DEC
ACC CRU DEC
HC
CO
NOX
CAH 7/77

Figure 10

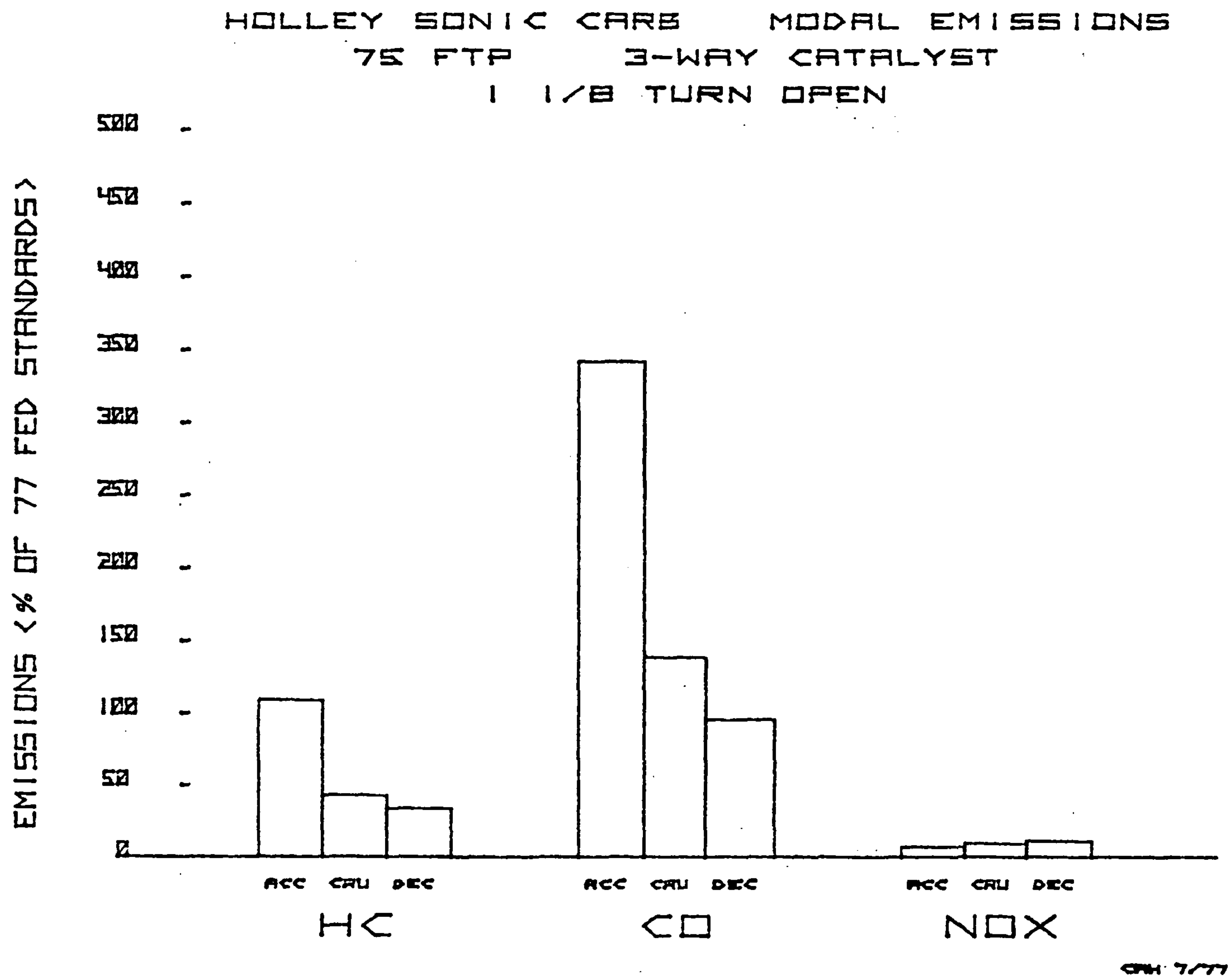
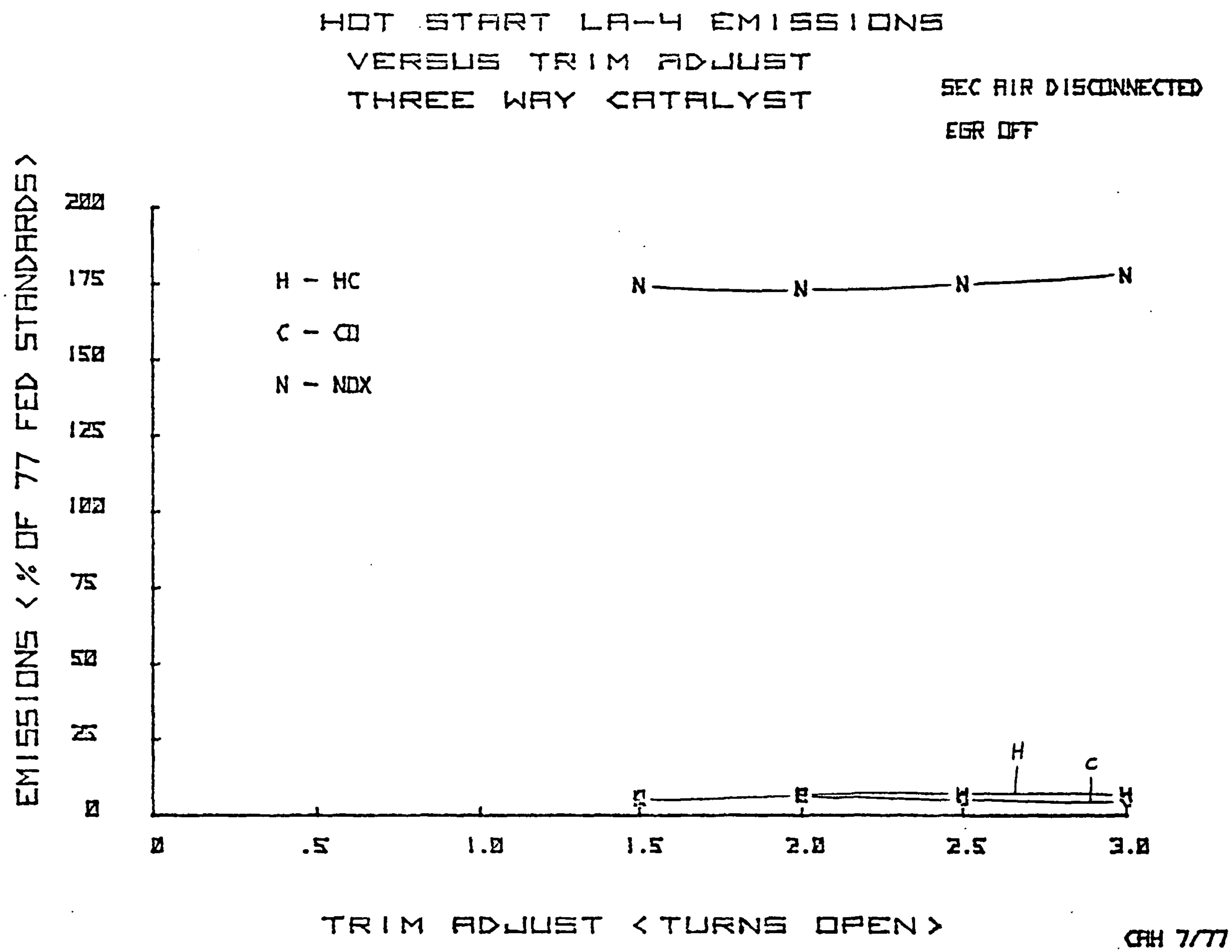

HOLLEY SONIC CARB MODAL EMISSIONS
75 FTP 3-WAY CATALYST
1 1/8 TURN OPEN
EMISSIONS (% OF 77 FED STANDARDS)
500
450
400
350
300
250
200
150
100
50
0
ACC CRU DEC
ACC CRU DEC
ACC CRU DEC
HC
CO
NOX
CRH 7/77

Figure 11



HOT START LA-4 EMISSIONS
VERSUS TRIM ADJUST
THREE WAY CATALYST
SEC AIR DISCONNECTED
EGR OFF
EMISSIONS <% OF 77 FED STANDARDS>
H - HC
C - CO
N - NOX
200
175
150
125
100
75
50
25
0
0
.5
1.0
1.5
2.0
2.5
3.0
TRIM ADJUST <TURNS OPEN>
CAH 7/77

Figure 12

Table 1
'75 FTP Mass Emissions
Oxidation Catalyst with EGR Activated After 70 Seconds

Test Number	HC g/km	HC (g/mi)	CO g/km	CO (g/mi)	CO_2 g/km	CO_2 (g/mi)	NOx g/km	NOx (g/mi)	Fuel Consumption litres/100 km	Fuel Consumption (miles/gal)
2 3/4 T.O., 5% Idle Enrich, No Secondary Air										
77-5349	.45	(.73)	4.98	(8.01)	362	(582)	.84	(1.35)	15.8	(14.9)
78-0331	.32	(.51)	2.64	(4.24)	337	(543)	.63	(1.02)	14.6	(16.1)
78-0350	.32	(.52)	3.98	(6.41)	356	(572)	.83	(1.33)	15.5	(15.2)
78-0384	.35	(.56)	4.59	(7.39)	356	(573)	.92	(1.48)	15.6	(15.1)
78-0446	.25	(.41)	3.27	(5.26)	342	(551)	.71	(1.15)	14.9	(15.8)
78-0469	.30	(.49)	3.10	(4.98)	343	(552)	.73	(1.17)	14.9	(15.8)
78-0483	.32	(.52)	3.51	(5.65)	336	(541)	.80	(1.29)	14.6	(16.1)
Average	.33	(.53)	3.72	(5.99)	347	(559)	.78	(1.26)	15.1	(15.6)
0 T.O. 0% Idle Enrich, with Sec. Air										
78-0548	.37	(.60)	14.79	(23.80)	360	(580)	.40	(0.65)	16.4	(14.3)
78-1418	.39	(.63)	13.34	(21.47)	373	(600)	.38	(0.61)	16.8	(14.0)
Average	.38	(.62)	14.07	(22.64)	367	(590)	.39	(0.63)	16.6	(14.2)
1/2 T.O.										
78-1288	.31	(.50)	6.18	(9.95)	336	(541)	.78	(1.25)	14.8	(15.9)
78-1321	.30	(.49)	3.95	(6.36)	364	(585)	.75	(1.20)	15.8	(14.9)
78-1416	.30	(.49)	3.70	(5.95)	361	(581)	.72	(1.16)	15.7	(15.0)
Average	.30	(.49)	4.61	(7.42)	354	(569)	.75	(1.20)	15.4	(15.3)
1 T.O.										
78-0775	.27	(.44)	4.54	(7.31)	342	(550)	.88	(1.41)	14.9	(15.8)
78-1420	.35	(.56)	2.01	(3.23)	360	(579)	.83	(1.33)	15.6	(15.1)
Average	.31	(.50)	3.28	(5.27)	351	(565)	.85	(1.37)	15.2	(15.5)
2 T.O.										
78-0845	.35	(.57)	2.39	(3.85)	339	(545)	.90	(1.45)	14.7	(16.0)
78-1548	.26	(.42)	4.51	(7.25)	354	(570)	.85	(1.37)	15.5	(15.2)
Average	.31	(.50)	3.45	(5.55)	347	(558)	.88	(1.41)	15.1	(15.6)
0 T.O. No Sec. Air										
78-0526	1.53	(2.46)	56.25	(90.5)	272	(438)	.35	(0.57)	15.6	(15.1)
2 1/4 T.O.										
78-0447	.37	(.59)	3.98	(6.40)	336	(541)	.72	(1.16)	14.7	(16.0)
3 T.O.										
78-1025	.42	(.67)	1.95	(3.13)	357	(574)	.60	(0.97)	15.4	(15.3)
78-1582	.42	(.68)	8.23	(13.25)	352	(567)	.73	(1.18)	15.7	(15.0)
Average	.42	(.68)	5.09	(8.19)	355	(571)	.67	(1.08)	15.5	(15.2)

Table 2
Steady State Emissions
3-way Catalyst with EGR
0% Idle Enirchment No Secondary Air

35 mph	HC (ppm)	CO (ppm)	CO_2 (ppm)	NOx (ppm)
0 T.O.	1688	1.49	12.78	4.66
1/4 T.O.	1200	0.45	13.35	3.50
3/8 T.O.	50	0.0	13.60	90.0
1/2 T.O.	73	0.0	13.50	150.0

1 Turn Open		HC		CO		CO_2		NOx		Fuel Consumption	
Speed	Test #	g/km	(g/mi)	g/km	(g/mi)	g/km	(g/mi)	g/km	(g/mi)	litres/100 km	(miles/gal)
Idle*	78-1696	.96	(.96)	2.52	(2.52)	5734	(5734)	6.72	(6.72)	2.46	(.65)
15		.02	(.03)	.01	(0.02)	234	(376)	.24	(0.38)	10.0	(23.6)
30		.11	(.17)	.48	(0.77)	168	(271)	.01	(.02)	7.2	(32.5)
40	78-1697	.02	(.03)	0.0	(0.0)	173	(278)	.44	(.71)	7.4	(31.9)
50		.02	(.03)	0.0	(0.0)	222	(357)	1.46	(2.35)	9.4	(24.9)

* grams/hour, liters/hour (gal/hour)

Table 3
'75 FTP Mass Emissions
3-Way Catalyst with EGR Activated After 70 Seconds, No Secondary Air

Test T.O.Number	HC g/km	HC (g/mi)	CO g/km	CO (g/mi)	CO_2 g/km	CO_2 (g/mi)	NOx g/km	NOx (g/mi)	Fuel Consumption litres/100 km	Fuel Consumption (miles/gal)
1/2(M) 5/4/77	.98	(1.58)	29.37	(47.25)	326	(524)	.05	(.08)		
5/8(M) 5/10/77	.57	(.92)	18.35	(31.13)	331	(533)	.14	(.22)		
3/4(M) 5/6/77	.80	(1.29)	24.21	(38.95)	339	(546)	.08	(.13)		
7/8(M) 5/14/77	.64	(1.03)	17.57	(28.27)	331	(532)	.11	(.18)		
1 (M) 5/12/77	.45	(.72)	13.16	(21.17)	321	(516)	.17	(.28)		
1 (M) 5/16/77	.66	(1.07)	18.99	(30.55)	334	(538)	.12	(.19)	14.4	(16.3)
1 (M) 5/18/77	.55	(.89)	17.49)	(28.14)	336	(541)	.14	(.23)	14.4	(16.3)
1 78-1692	.58	(.94)	17.88	(28.77)	329	(529)	.13	(.21)	15.3	(15.4)
1 78-1693	.68	(1.09)	16.43	(26.43)	331	(532)	.16	(.25)	15.3	(15.4)
1 1/8 (M) 5/13/77	.57	(.91)	16.62	(26.74)	327	(526)	.16	(.25)		
2 1/2 78-4175*	.48	(.77)	10.29	(16.55)	363	(584)	.32	(.52)	16.2	(14.5)
3 1/2 78-4683	.46	(.74)	12.22	(19.67)	362	(583)	.31	(.50)	16.3	(14.4)
NO EGR										
1 78-3820		(.43)		(9.87)		(535)		(3.25)		(16.1)

(M) Modal analyzer test data
* Small exhaust leak

Hot Start LA-4 Mass Emissions
3-Way Catalyst, No EGR, No Secondary Air

Test	HC		CO		CO_2		NOx		litres/100 km	(miles/gal)
1 1/2 78-3819	.05	(.08)	.53	(.85)	324	(521)	2.18	(3.50)	13.8	(17.0)
2 78-3818	.06	(.10)	.60	(.97)	322	(518)	2.16	(3.48)	13.8	(17.1)
2 1/2 78-3817	.06	(.10)	.52	(.84)	321	(516)	2.18	(3.51)	13.8	(17.1)
3 78-3816	.06	(.10)	.48	(.77)	318	(512)	2.22	(3.57)	13.6	(17.3)

Table 4
Steady State Mass Emissions
Oxidation Catalyst with EGR

	Test Number	HC g/km	HC (g/mi)	CO g/km	CO (g/mi)	CO_2 g/km	CO_2 (g/mi)	NOx g/km	NOx (g/mi)	Fuel Consumption litres/100 km	Fuel Consumption (miles/gal)
2 3/4 T.O., 5% Idle Enrich, No Secondary Air											
Idle*	77-5354	1.8	(1.8)	22.2	(22.2)	5317	(5317)	3.96	(3.96)	2.28	(.603)
10		.05	(.08)	.19	(.31)	322	(518)	.18	(.29)	13.8	(17.1)
20		.06	(.09)	.06	(.10)	181	(292)	.14	(.22)	7.7	(30.4)
30	77-5355	.11	(.17)	.03	(.05)	169	(272)	.11	(.17)	7.2	(32.6)
40		.07	(.11)	.02	(.03)	172	(277)	.24	(.39)	7.3	(32.0)
50		.06	(.09)	.02	(.04)	196	(315)	.37	(.59)	8.3	(28.2)
60	77-5356	.04	(.06)	.04	(.06)	231	(372)	.76	(1.22)	9.9	(23.8)
Idle*	78-0448		(1.1)	0.00	(0.00)	5237	(5237)	3.5	(3.5)	2.24	(0.591)
10		.04	(.07)	0.00	(0.00)	319	(514)	.17	(.28)	13.6	(17.3)
20		.06	(.09)	.01	(.01)	224	(360)	.16	(.26)	9.6	(24.6)
30	78-0449	.11	(.18)	.01	(.02)	180	(290)	.12	(.20)	7.7	(30.5)
40		.07	(.11)	.02	(.03)	175	(282)	.27	(.44)	7.5	(31.4)
50		.05	(.08)	.02	(.04)	186	(300)	.38	(.61)	7.9	(29.6)
60	78-0445	.03	(.05)	.04	(.07)	246	(396)	.63	(1.01)	10.5	(22.4)
0 T.O., 0% Idle Enrich, With Sec. Air											
Idle*	78-0549		(1.7)	2.9	(2.9)	6800	(6800)	11.5	(11.5	2.91	(0.769)
10		.07	(.11)	.14	(.22)	410	(660)	.62	(1.00)	17.6	(13.4)
20		.03	(.05)	.09	(.15)	216	(347)	.29	(.47)	9.2	(25.5)
30	78-0550	.07	(.12)	.06	(.09)	172	(277)	.21	(.33)	7.4	(32.0)
40		.06	(.09)	.07	(.12)	172	(276)	.48	(.77)	7.3	(32.1)
50		.05	(.08)	.07	(.12)	200	(322)	.88	(1.41)	8.5	(27.6)
60	78-0551	.04	(.07)	.19	(.30)	238	(383)	1.87	(3.01)	10.2	(23.1)
1 T.O.											
Idle*	78-0527		(.24)	0.00	(0.00)	5668	(5668)	7.32	(7.32)	2.42	(0.64)
15		.02	(.03)	0.00	(0.00)	233	(375)	.26	(.42)	9.9	(23.7)
30		.12	(.19)	.01	(.02)	173	(278)	.14	(.22)	7.4	(31.9)
40	78-0528	.09	(.14)	.01	(.02)	182	(293)	.30	(.49)	7.8	(30.2)
50		.07	(.11)	.02	(.04)	197	(317)	.52	(.84)	8.4	(27.9)
60		.05	(.08)	.03	(.05)	224	(360)	1.35	(2.17)	9.5	(24.7)

* grams/hour, liters/hour (gal/hour)

Table 5
Steady State Mass Emissions
Oxidation Catalyst with EGR, 0% Idle Enrichment

Speed	Test Number	HC g/km	HC (g/mi)	CO g/km	CO (g/mi)	CO_2 g/km	CO_2 (g/mi)	NOx g/km	NOx (g/mi)	Fuel Consumption litres/100 km	Fuel Consumption (miles/gal)
2 T.O., With Secondary Air											
Idle*	78-0846	.90	(.90)	0.00	(0.00)	5243	(5243)	4.60	(4.60)	2.23	(.59)
15		.04	(.07)	0.00	(0.00)	245	(395)	.21	(.33)	10.5	(22.5)
30		.16	(.26)	.02	(.04)	183	(295)	.11	(.17)	7.8	(30.0)
40	78-0847	.13	(.21)	.04	(.06)	184	(296)	.19	(.31)	7.9	(29.9)
50		.07	(.12)	.04	(.06)	207	(333)	.34	(.55)	8.8	(26.6)
60		.04	(.06)	.05	(.08)	229	(368)	.72	(1.16)	9.8	(24.1)
2 1/4 T.O.											
Idle*	78-0519	1.08	(1.08)	0.00	(0.00)	4540	(4540)	3.16	(3.16)	1.94	(0.513)
10		.05	(.08)	0.00	(0.00)	311	(501)	.16	(.26)	13.3	(17.7)
20		.07	(.11)	0.00	(0.00)	173	(278)	.14	(.23)	7.4	(31.9)
30	78-0520	.10	(.16)	.02	(.03)	165	(265)	.09	(.15)	7.0	(33.4)
40		.10	(.16)	.02	(.04)	185	(297)	.19	(.31)	7.9	(29.9)
50		.05	(.08)	.03	(.05)	186	(299)	.30	(.49)	7.9	(29.6)
60	78-0551	.02	(.04)	.04	(.06)	234	(376)	.62	(.99)		(23.6)
3 T.O., No Secondary Air											
Idle*	78-1027	1.00	(1.00)	0.00	(0.00)	5179	(5179)	3.80	(3.80)	2.20	(0.58)
15		.03	(.05)	0.00	(0.00)	226	(364)	.14	(.22)	9.6	(24.4)
30		.14	(.22)	.02	(.03)	177	(285)	.09	(.15)	7.6	(31.0)
40		.10	(.16)	.03	(.05)	182	(293)	.17	(.27)	7.8	(30.2)
50		.05	(.08)	.04	(.07)	206	(332)	.27	(.44)	8.8	(26.7)
60		.02	(.04)	.04	(.07)	233	(375)	.46	(.74)	9.9	(23.7)

*grams/hour, liters/hour (gal/hr)

Table 6
Highway Fuel Economy Test
With EGR

Test Number	HC g/km	HC (g/mi)	CO g/km	CO (g/mi)	CO_2 g/km	CO_2 (g/mi)	NOx g/km	NOx (g/mi)	Fuel Consumption liters/100 km	Fuel Consumption (miles/gal)
2 3/4 T.O. Oxidation Catalyst, 5% Idle Enrich, No Secondary Air										
77-5351	.11	(.18)	.08	(.13)	273	(440)	.56	(.90)	11.7	(20.1)
77-5352	.03	(.05)	.14	(.23)	244	(393)	.44	(.71)	10.5	(22.5)
77-5353	.06	(.10)	.39	(.62)	245	(395)	.58	(.94)	10.5	(22.4)
77-5411	.04	(.06)	.17	(.28)	249	(401)	.62	(1.00)	10.6	(22.1)
78-0386	.09	(.14)	.17	(.27)	245	(395)	.66	(1.06)	10.5	(22.4)
78-0388	.07	(.11)	.45	(.72)	232	(373)	.60	(.96)	9.9	(23.7)
78-0470	.06	(.09)	.04	(.07)	239	(385)	.60	(.96)	10.2	(23.0)
Average	.06	(.10)	.21	(.33)	247	(397)	.58	(.93)	10.5	(22.3)
0 T.O., 0% Idle Enrich, With Sec. Air										
78-1417	.06	(.09)	.24	(.39)	236	(379)	.98	(1.57)	10.1	(23.4)
78-1419	.06	(.10)	1.47	(2.36)	237	(381)	.76	(1.22)	10.2	(23.0)
Average	.06	(.10)	.86	(1.38)	236	(380)	.87	(1.40)	10.1	(23.2)
1 T.O.										
78-1421	.06	(.09)	.07	(.11)	234	(376)	.90	(1.45)	10.0	(23.6)
2 T.O.										
78-1322	.05	(.08)	.16	(.25)	229	(368)	.90	(1.45)	9.8	(24.1)
3 T.O.										
78-1583	.06	(.10)	.54	(.87)	239	(384)	.75	(1.20)	10.2	(23.0)
1 T.O. 3-way Catalyst, No Sec. Air.										
78-1691	.12	(.20)	3.90	(6.27)	215	(346)	.38	(.61)	9.4	(24.9)
78-1694	.12	(.19)	2.69	(4.33)	223	(359)	.52	(.84)	9.7	(24.2)
78-1695	.10	(.16)	2.18	(3.51)	213	(343)	.50	(.81)	9.3	(25.4)
78-1698	.10	(.16)	2.81	(4.52)	217	(349)	.52	(.83)	9.4	(24.9)
Average	.11	(.18)	2.90	(4.66)	217	(349)	.48	(.77)	9.4	(24.9)

Table 7
Baseline Data
Holley Tests of Production Vehicle After 4000 Mile AMA Durability
'75 FTP

HC		CO		NOx		Fuel Consumption	
g/km	(g/mi)	g/km	(g/mi)	g/km	(g/mi)	liters/100 km	(miles/gal)
.20	(.33)	1.4	(2.3)	0.6	(0.9)	13.6	(17.3)
.22	(.36)	1.7	(2.6)	0.6	(0.9)	12.4	(18.9)
.43	(.70)	1.3	(2.0)	0.6	(1.0)	13.0	(18.1)
.30	(.48)	1.3	(2.1)	0.6	(0.9)	12.7	(18.5)
.28	(.45)	1.6	(2.5)	0.6	(1.0)	12.6	(18.7)
Average:							
.29	(.46)	1.5	(2.3)	0.6	(0.9)	12.9	(18.3)
						HFET	
						9.2	(25.6)
						9.1	(25.9)
						8.9	(26.4)
						9.0	(26.0)

Table 8
Percent Contribution to '75 FTP Composite Emissions
(Cold Transient)

Oxidation Catalyst

Trim Adjust (Turns Open)	Secondary Air	HC	CO	NOx
2 3/4*	No	68	74	27
0	Yes	48	48	29
1/2	Yes	61	65	33
1	Yes	70	62	31
2	Yes	75	85	28
0	No	31	28	28
2 1/4	No	77	77	30
3	No	70	62	33

Three-Way Catalyst

Trim Adjust (Turns Open)	Secondary Air	HC	CO	NOx
1/2	No	31	34	71
5/8	No	39	43	28
3/4	No	37	38	44
7/8	No	34	34	37
1	No	44	36	42
1 1/8	No	36	41	34
2 1/2	No	58	46	32
3 1/2	No	54	50	32

Table 9

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1975 Dodge Dart
Emission control system - Sonic Carburetor, Catalyst, Air Injection, EGR

Engine

type	4 stroke, Otto cycle, I-6, ohv
bore x stroke	3.41 in. x 4.12 in. (87 mm x 105 mm)
displacement	225 cu in. (3687 cc)
compression ratio	8.4:1
maximum power @ rpm	100 hp @ 3600 (75 kW)
fuel metering	Holley sonic carburetor - model 1985 (baseline, Holley 1 bbl carb - model 1945)
fuel requirement	unleaded; tested with Indolene HO, unleaded, with 0.03 wt.% sulfur

Drive Train

transmission type	3 speed automatic
final drive ratio	3.23

Chassis

type	front engine, rear wheel drive
tire size	D78-14
curb weight	3100 lb (1405 Kg)
inertia weight	3500 lb (1587 Kg)
passenger capacity	5

Emission Control System

basic type	oxidation catalyst, air injection, back pressure modulated EGR
additional features	sonic carburetor; also tested with 3-way catalyst.