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Effect of Load Simulation on Auto Emissions and Model Performance

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Results from tests on a Chevrolet Celebrity (3000 pounds gross vehicle weight) indicated that emissions during tests with water brake load simulation did not differ significantly from those during tests with actual road load simulation. For the Celebrity, the load applied by the water brake with the tire rolling resistance losses on the dynamometer was approximately equal to the actual road load measured in highway tests.

Evaluation of the Modal Model was completed by comparing actual emissions data with predicted values. The Celebrity was used to generate emissions data for the New York City Cycle, the Surveillance Driving Schedule, and the Federal Test Procedure. Results indicated that the Modal Model was unable to accurately predict emission rates for the Celebrity.

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EFFECT OF LOAD SIMULATION ON AUTO EMISSIONS AND MODEL PERFORMANCE

by
Peter Gabele and Richard Snow

Emissions Measurement and Characterization Division
Environmental Sciences Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

NOTICE

PREFACE

Ambient standards for air pollutants exist for the protection of humans and their environment. Adequate planning is necessary to assure compliance with standard levels. But unless communities are able to predict in advance the cause and effect relationships which take place when emission sources arrive on scene, planning for a clean and healthy environment becomes unmanageable.

Models for predicting emissions from automobiles have been developed and promulgated by the EPA. These models are used extensively by states to develop scenarios for environmental planning. The Environmental Sciences Research Laboratory contributes to the formulation of predictive models by providing emission factors from mobile sources. Because emission control technology progresses with time, emission factors and the methodology used to obtain them must be updated periodically.

This report evaluates the effectiveness in predicting current vehicles' emissions of an emission rate model which is used widely throughout the United States. It also examines the dynamometer test procedure which is used to obtain automobile emission factors.

ABSTRACT

The overall objective of this study was to identify sources which might contribute to errors in mobile source emission rate model predictions. The effect of road load simulation on exhaust emissions was examined and an evaluation of the U.S. Environmental Protection Agency's Automobile Exhaust Emission Modal Model was conducted. The Modal Model is a component of the Intersection Midblock Model and MOBILE2, two widely used programs for predicting emissions from mobile sources.

Results from tests on a Chevrolet Celebrity (3000 pounds gross vehicle weight) indicated that emissions during tests with water brake load simulation did not differ significantly from those during tests with actual road load simulation. For the Celebrity, the load applied by the water brake with the tire rolling resistance losses on the dynamometer was approximately equal to the actual road load measured in highway tests.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

A/D	analog to digital
CFM	cubic feet per minute
CVS	constant volume sampler
FTP	Federal Test Procedure
HC(s)	Hydrocarbon(s)
IMM	Intersection Midblock Model
NO_x	nitrogen oxides
NYCC	New York City Cycle
SDS	Surveillance Driving Schedule
SS	steady state
rpm	revolutions per minute
VMT	vehicle miles traveled

SECTION 1

INTRODUCTION

Ambient air concentrations of carbon monoxide (CO) within urban areas are often significantly higher than those predicted by dispersion models. Because CO is emitted predominantly by motor vehicles, models used to predict CO emission rates from groups or classes of motor vehicles could be contributing substantially to the shortfall and should be examined for obvious inaccuracies. Two widely used models or programs for estimating emissions concentrations for hydrocarbons(HCs), nitrogen oxides (NO_x), and CO are MOBILE2 (1) and the Intersection Midblock Model(IMM) (2).

MOBILE2 was developed by EPA using data acquired over 12 years of emissions testing. Because the bulk of emissions data was collected for the Federal Test Procedure (FTP), other models are used within MOBILE2 to correct emission rates to non-FTP conditions. For example, the EPA Modal Analysis Model is used to estimate emission rates for vehicles operating over driving cycles with average speeds different from the FTP. These emission rates are used to develop speed correction factors for correcting FTP data to the specific case being modeled.

The Intersection Midblock Model (IMM) was also developed by EPA to aid in the identification and analysis of CO hot spot locations. It uses the EPA Modal Analysis Model to calculate CO emissions due to vehicle cruising, acceleration-deceleration (accel-decel), and assigns these emissions to traffic links based upon calculated intersection parameters. After emissions have been distributed among individual lanes of each link, the EPA HIWAY Model is used to predict CO ambient concentrations at the desired locations.

One questionable component of both models is the EPA Modal Analysis Model which is designed to predict emission rates for specific vehicles being operated over any defined driving schedule. The Modal Analysis Model was developed in 1973 using data obtained on pre catalyst cars. Although it was later refined and updated to 1977 model-year cars, the model remains outdated in the context of automotive pollution control advances which have occurred since that time.

Additionally, the emissions used to develop the Modal Model were obtained from tests on water brake rather than electric dynamometers. Although the test procedures using water brake dynamometers is an adequate method for emissions certification, it is unable to simulate vehicle road loads as accurately as an electric dynamometer (3,4).

Both the Modal Model and dynamometer load simulation technique should be examined for obvious inaccuracies. If inaccuracies exist, compensatory methods or techniques can, hopefully, be applied to reduce errors and improve model quality.

The objectives of this experimental program are to investigate contentions that water brake dynamometers fail to accurately simulate vehicle road loads during tests and to evaluate the Modal Model's ability to effectively predict emission rates for new cars. The effect of water brake dynamometer loading on exhaust emissions was measured for three driving cycles: the FTP, the Surveillance Driving Schedule (SDS), and the New York City Cycle (NYCC). For each cycle, emission rates measured at actual road load were compared with those measured for water brake load. Examination of the Modal Model involved comparing emission rates predicted by the model with those actually measured. Predictions made for Test Phases 2 and 3 of the FTP, the SDS, and NYCC were compared with measured emissions data that had been obtained during the load study phase of the program.

SECTION 2

CONCLUSIONS

Investigation of the effect of dynamometer load characteristics upon regulated emission rates and an evaluation of the EPA Modal Analysis Model were completed. Based upon the study's findings the following is concluded:

1. The load applied by the water brake and the tire rolling resistance losses on the dynamometer was approximately equal to the actual road load measured in highway tests.

2. Regulated emission rates for the Celebrity are not significantly different when tested using the water brake simulation versus actual road load simulation on an electric dynamometer.

3. The EPA Exhaust Emissions Modal Model is an inaccurate predictor of regulated emissions from the Celebrity.

The conclusions suggest that water brake dynamometers adequately simulate actual road loads for emissions test purposes. This should hold true for vehicles such as the Celebrity which have large inertia load components relative to aerodynamic load components. When the aerodynamic load component becomes a significant portion of the total road load, dynamometer absorbed power theoretically deviates with speed from the actual road load. The tendency for this occurrence, which makes simulation of road loads with water brake dynamometers more difficult, increases for extremely lightweight cars.

Because most data collected for use in MOBILE2 have been from vehicles roughly equal in size to or larger than the Celebrity, inaccuracies in load simulation do not have any significant effect on the accuracy of MOBILE2. However, should minicars (<2000 lb) ever occupy a significant percentage of the vehicle miles traveled (VMT), a re-evaluation of dynamometer load simulation will become necessary.

With regard to the Modal Model evaluation, results in tests on only one vehicle cannot in themselves disprove the model. This is true because the model was recommended for prediction of vehicle group emissions and not individual vehicle emissions (5). However, because high tech emission control systems have changed the relationship between vehicle speed and emissions since the model's development, the Modal Model should be updated.

SECTION 3

RECOMMENDATIONS

It is suspected that the Modal Model is an inaccurate predictor of regulated emissions from late model cars which are equipped with high tech emission control systems. Because this model plays an active role in both MOBILE2 and the IMM, it should be updated or, if necessary, replaced with an acceptable alternative method.

In the case of MOBILE2, speed correction factors are now being obtained using actual emission test results rather than results predicted using the Modal Model. This requires testing a rather large cross section of vehicles over test cycles having different average speeds. These data will be used in developing realistic speed correction factors for use in MOBILE3, an upcoming revision of the current MOBILE2.

SECTION 4

EXPERIMENTAL PROCEDURES

FACILITY DESCRIPTION

All emissions tests were conducted with a chassis dynamometer for vehicle road load simulation. The Horiba model CD6-800/DMA-915 dynamometer simulated road load by means of a DC electric motor-generator directly coupled to the front rolls of the dynamometer. A control system was used to vary armature current to achieve the desired motor torque. In addition to vehicle road load simulation, the electric drive was capable of simulating vehicle inertia as 1-lb increments. Rolls of the dynamometer are 22 cm (8.65 in.) in diameter and are coupled during the automatic calibration mode.

Exhaust gases from the test vehicle were directed via a flexible 7.6 cm (3-in.) stainless steel line to a 45.7-cm (18-in.) diameter dilution tunnel (Figure 1). A Constant Volume Sampling System (CVS) located at the rear of the dilution tunnel drew diluent and exhaust gas at a rate of about 700 CFM.

Regulated gaseous emissions and carbon dioxide (CO_2) were determined using standard bag sampling and analysis procedures in accordance with the Federal Register (6). In selected test runs, these same emissions were measured using a real-time computer system to obtain modal emissions data. The real-time system, which has been previously described (7), centered around operation of a Texas Instruments 960B minicomputer. Analyzer response times, which vary with exhaust gas flow rate, were determined with the aid of a flow measuring device at the engine air inlet. Analog outputs from the gas analyzers were directed to the computer through analog to digital (A/D) converters. In addition to gas data, modal calculations of CVS flow rates corrected to standard atmospheric conditions were also determined.

TEST VEHICLE

The test vehicle used in this study, a 1982 model year, Chevrolet Celebrity with a 2.5-l, in-line, 4-cylinder engine is described in Table 1. The engine was fitted with throttle-body fuel injection, and engine exhaust gases were treated in a three-way single bed catalytic converter. The vehicle was equipped with cruise control, which was used during steady speed testing.

In order to measure torques required to operate the vehicle during road and dynamometer testing, wheel torque sensors were instrumented on both front drive wheels. Signals from each sensor were transmitted to a strain gauge conditioner which provided an analog output signal as well as a calibration feature. Torque signals were stored on tape using a four channel, frequency-modulated instrumentation recorder which was powered off the vehicle's DC system.

TABLE 1. TEST VEHICLE DESCRIPTION

Vehicle	Chevrolet Celebrity
Model year	1982
Engine type	L4
Displacement (1)	2.5
Carburetion	EFI (Throttle-body)
Emission control	3-Way catalyst
Inertia Weight, (lbs)	3500
Compressions ratio	8.2
Net HP @ RPM	112/4800
Transmission	Auto
Number of Doors	Four
Odometer (mi)	10,000

During the road tests a fifth wheel was used to measure vehicle speed. The speed signal was transmitted into a separate channel on the tape recorder to enable calculation of load or power since power is a function of torque and speed.

All testing was done using the Goodyear Viva II steel belted radials with which the car came equipped. Tire inflation pressures were held at about 35 psi during road tests and 45 psi on the dynamometer. All tires had been driven about 10,000 mi before the test program began.

EXPERIMENTAL DESIGN

The experimental program involved three stages: (1) electric dynamometer simulation of actual road and water brake dynamometer loads, (2) emissions testing, and (3) computer model predictions. Each stage required completion before the following stage could proceed.

Dynamometer Road Load Simulations

In the initial stage, the actual road load for the test vehicle was determined through road testing. Wheel torques and vehicle speeds were recorded in both directions on a level stretch of highway located on U.S. Route 64 at the Lake Jordan Dam Project. The test section extended for about 2000 ft with a .02 % grade. On the day of testing the wind speeds, which were measured by hand-held anemometer, at no time exceeded 1 knot. Low wind speeds and dry weather created nearly ideal conditions for testing road loads.

In order to develop the required speed-load relationship, the loads on the vehicle were measured using cruise control at steady speeds ranging from 70 to 30 mph in 10-mph increments. An additional load point at 15 mph was taken without cruise control. All tests were run in both directions and some of the tests were repeated. Points at 70, 30, and 15 mph were rerun after the entire test sequence in order to determine test repeatability.

For each of the speeds examined, load (horsepower) values were calculated as a function of the average torque multiplied by the wheel revolutions per minute (rpm). Speed-load points were fed into a computer which provided a best fit quadradic equation using a nonlinear least squares method. The resultant speed-load equation or curve represented the actual road load case. A previously described procedure for determining road load with wheel torque meters (4) was generally adhered to in this study.

After the actual road load equation had been determined, it was programmed into the electric dynamometer and the vehicle was tested. Wheel torque and rpm measurements were made so that a new speed-load equation could be obtained. This represented the actual road load simulated by the dynamometer plus tire rolling resistance losses on the dynamometer rolls. To compensate for added rolling resistance losses, a new equation was obtained by subtracting the tire losses (power measured at the wheels minus power being absorbed by the dynamometer) from the actual road load equation. The resulting equation was then used to simulate loads which when added to tire rolling resistance losses on the dynamometer closely approximated actual road loads. Some slight adjustments were made to the coefficients of the aerodynamic and rolling resistance terms to more closely simulate the actual case.

Once the actual road load curve could be accurately reproduced on the dynamometer, an equation for programming water brake loads was sought. Coast-down data from a Clayton water brake dynamometer located at EPA, Ann Arbor, was used to develop the necessary water brake speed-load relationship. Horiba, Inc., the electric dynamometer manufacturer, had also provided an equation which could be used to simulate water brake loads. This curve, while found to be almost identical to the one derived from data supplied by EPA, Ann Arbor, was not used in the program except as a verification device.

Dynamometer Inertia Simulation

Most chassis dynamometers employ flywheels to simulate vehicle inertia loads. More recently, however, electric dynamometers have dispensed with flywheels and instead use electric simulation. Many versions provide inertia selections in 1-lb increments, a feature not practical with flywheels. But the principal argument in favor of flywheel elimination is the obvious space-saving advantage.

The inertia setting for the Chevrolet Celebrity was 3000 lb. While this value was used in emissions certification, it was somewhat less than the total effective mass (gravitational plus rotating component) as tested on the road. The rotating component, estimated from data obtained previously on a similar car (8), plus the weight of the vehicle, test equipment, and test personnel was about 3500 lb.

To measure the accuracy of dynamometer inertia simulation, a group of 0 to 60 mph wide-open throttle accelerations were run on both the level road and the dynamometer. Integrated torque values measured during the accelerations were compared in each case to determine accuracy of dynamometer inertia simulation. Because the actual vehicle weight accelerated on the road was about 3500 lb., dynamometer inertia simulation was set at this value.

Emissions Testing

In the second stage of the experimental program, emissions tests were run on the dynamometer. The test matrix which was followed is shown in Table 2. Exhaust emission rates were measured for three test cycles and two load conditions. The test cycles were the FTP, NYCC, and the SDS, and the load conditions were actual road load and water-brake load. Real-time emission testing was used with the SDS because modal data from that cycle were required by the model to predict emission rates for other cycles.

TABLE 2. TEST MATRIX*

Test Cycle		Actual road simulation	Water brake simulation	Real time system
1st Day				
	FTP	X		
	NYCC	X		
	NYCC		X	
	SDS		X	X
	SDS	X		X
	SDS	X		X
	SDS		X	X
2nd Day				
	FTP		X	
	NYCC		X	
	NYCC	X		
	SDS	X		X
	SDS		X	X
	SDS		X	X
	SDS	X		X

* Sequence repeated six times

Test Cycle Descriptions--

Of the three test cycles or driving sequences examined in this study, the FTP is most familiar to those in the automotive emissions control field. It represents a typical urban driving schedule which has been adopted by EPA in its certification procedure. Total distance of the FTP is 7.5 mi and average speed is 19.6 mph. The cycle contains three distinct phases--cold transient, hot stabilized, and hot transient-- and each phase has its characteristic emissions. A more detailed description of the FTP is given in the Federal Register.

The NYCC (sometimes referred to as the New York City Driving Cycle) represents a typical Manhattan driving experience. The cycle is characterized by low speeds, very high accelerations, frequent stops, and a 40% idle time. Total distance of the NYCC is 1.2 mi with an average speed of 7.1 mph.

The SDS, unlike the FTP and NYCC, does not represent routine driving but is designed to measure vehicle emissions over a variety of steady state and transient driving conditions. To accomplish this the SDS contains 37 distinct modes: 32 at differing accel/decel rates which originate at different speeds and 5 at steady state speeds of 0, 15, 30, 45, and 60 mph. Acceleration and deceleration rates covered within the driving sequence represent the full range of rates observed in the CAPE-10 car-chase study (9).

Except for the FTP in which the car was started cold following an overnight soak period, each of the cycles was run following a hot soak period of 10 min. A brief summary of the three driving cycles discussed above is shown in Table 3.

TABLE 3. TEST CYCLE DESCRIPTIONS

Test Cycle	Cold Start	Avg. Speed	Stops Per Mi	Total Distance	Duration (min)	% Time Idle
FTP	Yes	19.6	2.40	7.5	22.9	19.0
NYCC	No	7.1	9.32	1.2	10.0	35.2
SDS	No	33.5	0.82	9.8	17.6	11.7

Computer Model Predictions--

Following the emissions testing stage, data from the SDS were available for use in the Modal Model to arrive at emission rate predictions. The Modal Model formulated an instantaneous emission rate function for the vehicle, which was used to calculate second-by-second emissions over any given speed versus time driving sequence. Integration of these emission rates resulted in predicted values for the emissions over the entire test cycle or portions thereof.

The emission rate function which was developed within the model was based on assumptions that steady state emission rates are a quadratic function of speed, that acceleration is a perturbation to the steady state emission rate function, and that quadratic functions of acceleration represent good approximations to the perturbation (5). Two mathematical expressions are used to define the emission rate function, one representing the steady state function and one representing the non-steady state or transient function. Taken together, the two functions require specification of 12 coefficients -- 3 for the steady state function and 9 for the transient functions.

Coefficient specification is accomplished through processing data obtained in 37 SDS modes. Data from the 5 steady state modes and from the remaining 32 accel/decel modes are used to define the transient function. Predictions of instantaneous emissions are carried out by joining the two functions with a weighting function. The weighting function, which is a function of acceleration, allows for a smooth transition between the steady state and the accel/decel emission rate functions.

Because modal data repeatabilities are poor, a sample of at least 25 SDS tests was obtained. For example, the relative standard deviation for 27 CO samples obtained in Mode 11 during replicate SDS tests was about 38%. Given 27 replicate results with a standard deviation of 38%, there is a 95% certainty that the mean emission rate calculated for Mode 11 will be within 15% of the true value. A complete listing of the means, standard deviations, and estimated errors for emission rates in each of the 37 SDS modes is shown in Table 4. It is noted that modal data exceeding two standard deviations were eliminated before the above statistics were performed.

Using mean emission rate values for each mode, the Modal Model was used to predict emission rates for Test Phases 2 and 3 of the FTP, the NYCC, and the SDS. Emissions predictions for each of the 38 SDS modes were also made. Predicted values were compared with measured values obtained in 12 FTP, 16 NYCC, and 27 SDS tests.

TABLE 4. MEANS, STANDARD DEVIATIONS, AND ESTIMATED ERRORS FOR EMISSION RATES. MEASURED IN 27 REPLICATE SDS TESTS.

Mode	Mean g/mi	Std. Dev. g/mi	Estimated error
1	10.5	5.2	18
2	0.7	0.6	32
3	8.8	5.2	22
4	4.3	2.1	18
5	6.8	3.7	20
6	0.6	0.5	33
7	173.2	31.1	6
8	3.7	1.4	14
9	33.5	22.0	24
10	0.6	0.2	14
11	43.6	16.6	14
12	0.6	0.2	13
13	33.0	17.2	19
14	0.6	0.3	21
15	0.1	0.1	43
16	0.9	0.7	30
17	4.1	2.7	24
18	0.1	0.1	34
19	22.6	15.7	26
20	0.1	0.1	24
21	137.0	29.8	8
22	0.8	0.3	15
23	2.1	1.2	22
24	14.2	12.1	32
25	0.7	0.4	22
26	0.1	0.2	57
27	6.3	7.3	44
28	0.6	0.3	20
29	1.9	1.6	31
30	73.5	21.5	11
31	1.1	0.5	18
32	0.1	0.1	36
33	1.7	0.6	13
34	1.3	0.7	20
35	1.2	0.5	17
36	1.0	0.3	11
37	3.7	1.6	17

*Estimated error = (Error/mean) x 100%.

SECTION 5

RESULTS AND DISCUSSIONS

ACTUAL ROAD LOAD DETERMINATION

Wheel torque data collected during road tests are shown in Table 5. The numbers represent average torque measured during the test run. Slightly higher values shown in runs headed north are related to a small (0.02%) positive grade in that direction. The torque data were collected at steady speeds ranging from about 15 mph to 70 mph. When the data were reduced, two speed-load curves were drawn up: one for speeds < 70 mph and one for speeds < 50 mph. Figure 2 shows the two curves, which are similar in shape, alongside each other. Equations for Curves A (<70 mph data) and B (<50 mph), respectively, are:

$$T = 37.2 - 0.17\ v + 0.024\ v^2 \qquad (A)$$

$$T = 26 + 0.83\ v + 0.008\ v^2 \qquad (B)$$

where: v = velocity in mph

T = torque in ft-lb

At 30 mph there is only a 2 ft-lb difference in torque (3.6%) between the two curves and at 50 mph a 3 ft-lb. difference (3.4%). Because most test cycles run in this program were at speeds <50 mph, Curve B was selected to provide actual road loads required for simulation.

DYNAMOMETER ROAD LOAD SIMULATION

Curve B was programmed into the dynamometer and the vehicle was readied for testing. With wheel torque meters in place, torque measurements were taken over the same steady speed points examined on the road. The speed-load relationship obtained is shown in Figure 3 as Curve C. The difference between Curve C and Curve B is due to tire rolling resistance losses on the dynamometer and is plotted as Curve D in Figure 3. When Curve D was subtracted from Curve C and the resulting relationship was programmed into the dynamometer, wheel torque values were again obtained and, after some slight adjustments to the dynamometer load equations, these values were plotted as Curve E in Figure 4. This load curve very closely simulates the load curve (Curve B) obtained in actual road testing.

TABLE 5. TORQUE DATA COLLECTED DURING ROAD TESTS

Speed (mph)	Direction	Torque (ft-lb)
68.9	N	150
67.6	N	143
70.9	S	145
67.9	S	135
67.1	S	128
59.4	N	114
58.9	S	106
49.5	N	88
49.0	S	82
40.3	N	76
39.4	S	67
31.7	N	61
30.1	N	65
30.9	S	53
28.9	S	52
14.4	N	41
15.0	N	41
14.7	S	40
14.3	S	36

DYNAMOMETER WATER BRAKE SIMULATION

The dynamometer manufacturer had furnished a load equation which could be used to simulate a water brake dynamometer. In addition, coast down data were available from one of the Clayton water brake dynamometers at the EPA in Ann Arbor. Since both curves were similar, it was arbitrarily decided to use the relationship developed from the EPA, Ann Arbor coast down data.

Wheel torque measurements obtained while the vehicle was undergoing water-brake-simulated loads accounted for tire rolling resistance losses on the dynamometer rolls in addition to dynamometer load. The load curve representing this condition is shown in Figure 5 with the actual road load curve previously obtained. While differences do appear at the low and high speed ends, overall the curves are not significantly different.

VEHICLE INERTIA LOAD SIMULATION

As a means of insuring accurate dynamometer simulation of vehicle inertia weight, integrated inertias were measured during wide-open throttle (WOT) accelerations on both the dynamometer and level road. The results are shown in Table 6.

TABLE 6. VEHICLE INERTIA MEASUREMENTS FOR 0 to 60 MPH WOT ACCELERATIONS

	Inertia Weight (lb)		Time (sec)	Integrated torque (ft-lb-sec)
Dynamometer	3000		16.4	8522
	3000		16.6	8569
	3500		19.1	10003
	3500		19.0	10043
Road (6 runs)	3500	*	$\bar{x}$ = 19.4	10909
		**	s = 2.2%	1.7%

* $\bar{x}$ = the mean of 6 runs.
** s = relative standard deviation.

At simulated inertia of 3000 lb. the integrated torque values fall about 15% below those at 3500 lb. The values obtained in dynamometer simulations of the loaded test car (3500 lb) are within 10% of those obtained on the roadway. Acceleration times are also shown in Table 6. While a decrease of about 15% again noted in going from 3500 lb to 3000 lb, a difference of only 2% is observed between dynamometer and roadway acceleration times. Indications are that the dynamometer is accurately simulating vehicle inertia load.

EMISSIONS TESTING

Emissions of HC, CO, NO_x, and CO_2 for the Celebrity were determined for three different tests cycles using actual road load and water brake load simulations. Because both load curves were similar, significant differences in emissions rates were not anticipated. Emissions data presented in Table 7 supported the expectation that no significant differences in emissions occur as a result of load parameter.

TABLE 7. EXHAUST EMISSIONS SUMMARY

Emission	Load simulation	FTP (g/mi)	NYCC (g/mi)	SDS (g/mi)
HC	Actual road	0.24(±.04)	0.77(±.23)	0.18(±.03)
	Water brake	0.23(±.04)	0.76(±.26)	0.17(±.03)
CO	Actual road	6.33(±.89)	10.91(±1.41)	15.84(±1.97)
	Water brake	6.83(±.26)	11.13(±1.77)	16.62(±2.3)
NO_x	Actual road	1.27(±.07)	2.06(±.35)	0.91(±.05)
	Water brake	1.25(±.09)	2.11(±.35)	0.93(±.06)
CO_2	Actual road	341.2(±3)	656.8(12.8)	308.5(±2.6)
	Water brake	348.9(±5)	557.7(±10.27)	307.8(±3.9)

Modal emissions data revealed no significant differences between the two imposed load conditions. However, large scatter, characteristic of data obtained in replicate modal analysis runs, completely masks any differences which might have existed modally (see Table 4). The purpose of obtaining modal data during the SDS was not so much to examine emissions differences because of load parameter changes as to evaluate the accuracy of Modal Model predictions.

MODEL PREDICTIONS

Emission rates for HC, CO, and NO_x were predicted for Test Phase 2 and 3 of the FTP, the NYCC, the SDS, and each of 38 modes of the SDS. Predictions were not made for Test Phase 1 of the FTP because cold start emissions cannot be successfully modeled by the Modal Analysis Model.

Table 8 shows the percentage error of predicted values compared to those actually measured. The negative values indicate that in all cases predictions are lower than measured values. For CO there is a trend of increasing error as average cycle speed increases. Generally, the error in predicting NO_x emission rates is lower than those for predicting CO and HC.

CO emission rate predictions for each SDS mode were compared with the calculated emission rates for those same modes. A summary of the results showing the error of the prediction is shown in Table 9. The negative values again indicate that with only one exception predictions are lower than measured values. For acceleration modes with average speeds over 30 mph predictions appear to be unreasonably low. Measured emission rates for these modes were the highest for the entire driving cycle while the predicted values were usually less than those for deceleration modes. Predictions for idle and 15 mph SS were very close to the measured values; however, those for 30 and 45 mph SS were rather low and high, respectively.

In general, predictions made by the EPA Modal Analysis Model were considerably lower than measured values. This was particularly apparent with CO predictions for driving cycles and SDS accel modes having average speeds over 30 mph. To further investigate this trend, a family of curves (see Figure 6) describing the emission rate function were drawn showing CO emissions as a function of velocity for accelerations ranging from 1.5 mph/s to 2.25 mph/s. For the Celebrity negative emission rates occur at frequent points within the model. Emissions, regardless of acceleration, appear about the same at 30 mph. Since these are physically impossible trends for the vehicle tested, the curves illustrate an obvious discrepancy in the model.

The percent errors as given in Tables 6 and 7 include test to test variability as well as the error in model predictions. Table 3 shows that in most cases test variability was rather high. It is also noted that the error percentages in Tables 6 and 7 do not translate directly to MOBILE2 which merely uses emission rate prediction to arrive at speed correction factors.

TABLE 8. PERCENTAGE ERROR OF PREDICTED VALUES TO ACTUAL MEASURED VALUES

Cycle	Avg. Speed (mph)	HC % error*	CO % error	NOx % error
NYCC	7.1	-83	-36	-68
FTP Phase 2	16.	-47	-46	0
FTP Phase 3	25.6	-63	-65	-27
SDS	33.5	-64	-90	-39

* % error = ((predicted-measured) ÷ measured) x 100%

TABLE 9. PERCENTAGE ERROR OR PREDICTED VALUES

Modes	CO, % error*
Accels >30 mph (10 modes)	-53
Accels <30 mph (7 modes)	-77
Decels (15 modes)	-54
Idle	-2
15 mph SS**	-2
30 mph SS	-70
45 mph SS	+50
60 mph SS	-15

* % error = ((predicted-measured) ÷ measured) x 100%.
** SS = Steady speed.

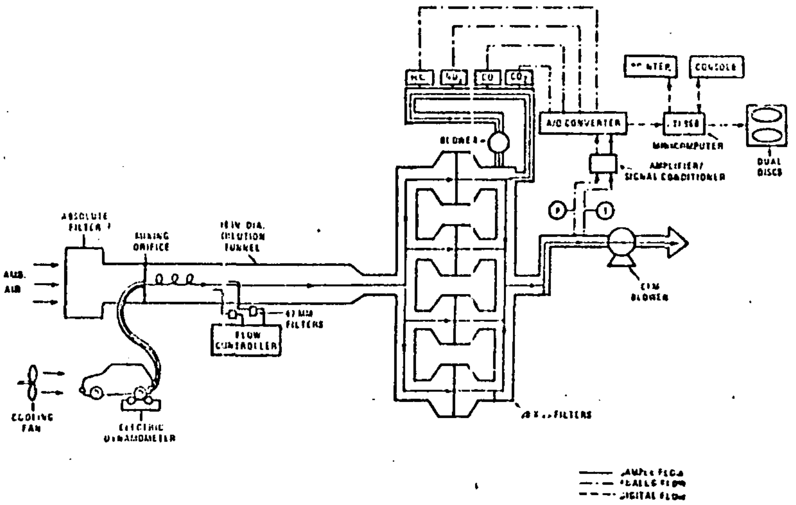

Figure 1. Sampling scheme.

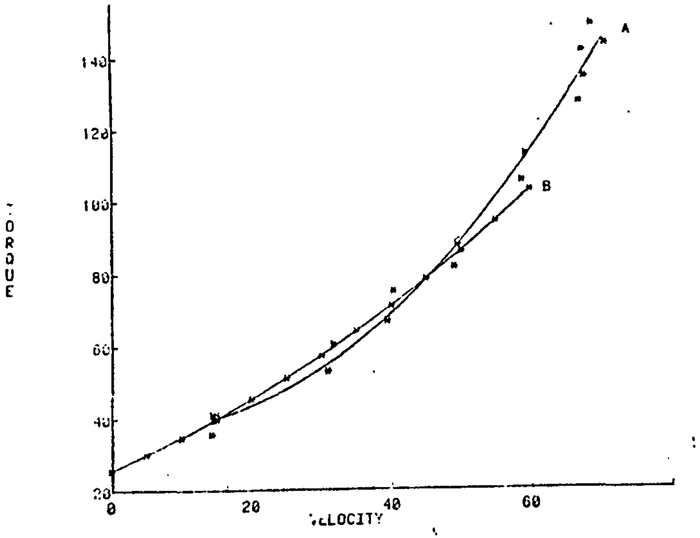

Figure 2. Actual road load curves: A for 70 mph and below, B for 50 mph and below.

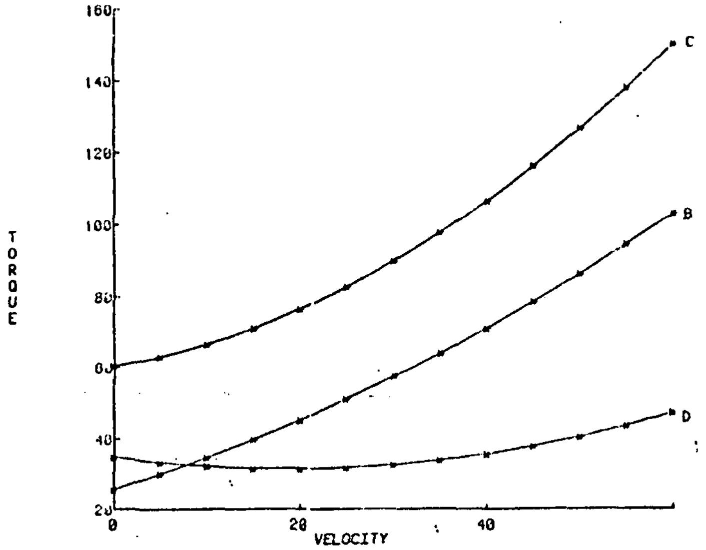

Figure 3. Actual road load curve (B), actual road load simulation plus rolling resistance losses on the dynamometer (c), rolling resistance losses on dynamometer (C-B=D).

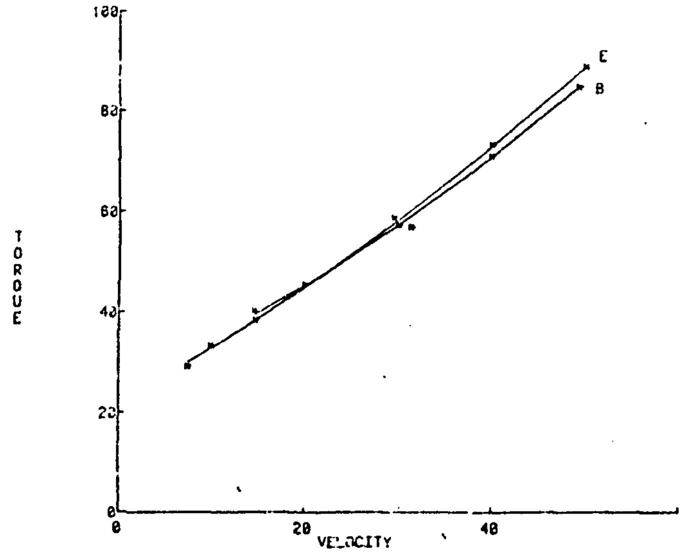

Figure 4. Actual road load and simulated actual road load curves (B and E).

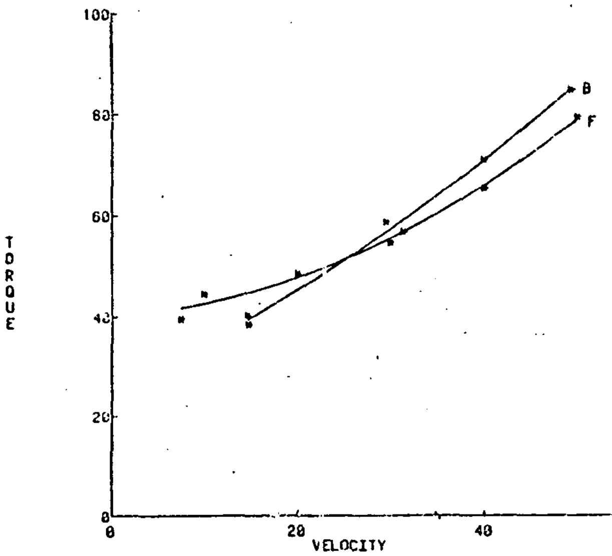

Figure 5. Actual road load (B) versus water brake load simulation (F).

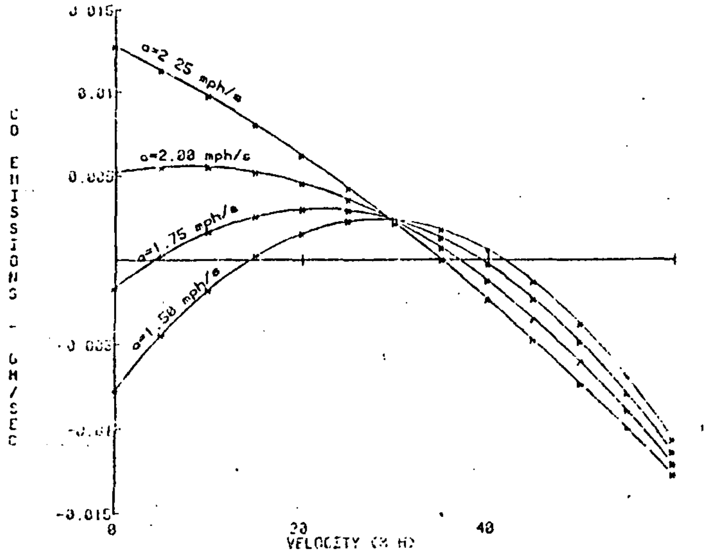

Figure 6. Emission rate function curves for accelerations held constant at 1.5 to 2.25 mph/s.