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Technical Report

A Track to Twin Roll Dynamometer Comparison of Several Different Methods of Vehicle Velocity Simulation

by

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NOTICE

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Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air, Noise and Radiation
U.S. Environmental Protection Agency

ABSTRACT

The current EPA test procedure for fuel economy and emissions testing uses a twin roll dynamometer, obtaining a speed signal from the rear roll and simulating the forces at the front roll. With the rolls coupled only by the drive wheels of the vehicle, the front roll travels approximately 2% slower than the rear roll at steady-state 50 mph, resulting in approximately a 4% overprediction of fuel economy. Coupling the rolls externally equalizes the roll speeds at a value which better simulates the road velocity and therefore better predicts the fuel economy. This report describes the test program and data analysis which led to these conclusions.

FOREWORD

The EPA has conducted a test program in order to determine the most representative method for simulating the road velocity of a vehicle on a Clayton twin-roll dynamometer. The three methods of simulating the road velocity on the twin-roll dynamometer are:

(1) Using the velocity of the rear roll, which is the current method,

(2) Using the velocity of the front roll,

(3) Operating with the rolls coupled.

To determine which of these three methods most closely represents the road experience of a vehicle, steady-state tests were conducted on a track and compared to dynamometer tests using each speed simulation method. The same vehicle was used for all phases of the test program. This report describes the test program, reports the results, and recommends the most appropriate method of velocity simulation on a twin-roll dynamometer.

SUMMARY

The results of the road to dynamometer comparison show that the road velocity is best simulated when the front and rear rolls of the dynamometer are coupled. With the rolls coupled, the simulated velocity was within 0.025% of actual road velocity. With the rolls uncoupled, the rear roll velocity over credited the vehicle speed by approximately 1.0% while the front roll under credited the speed by about 1.0%. Coupling the rolls reduced measured fuel economy by approximately 4% in comparison with the current method of using the rear roll speed. This is consistent with the 1% speed errors in each roll, since the force is proportional to the velocity squared. In conclusion, coupling the rolls is technically the best method of simulating the vehicle velocity and should improve EPA fuel economy predictions.

I. INTRODUCTION

When a vehicle is tested for fuel economy and emissions on a Clayton twin-roll dynamometer, there is a difference between the velocities of the front and rear rolls of the dynamometer.

Therefore, the speed sensor location can have a significant effect on fuel economy and emissions testing. Steady-state tests have shown that the rear roll travels approximately 1.0 mph faster than the front roll at 50 mph (1). This occurs because the drive wheels of the vehicle, which are cradled between the two rolls, act as the only coupling between the two rolls when a vehicle is driven on the dynamometer. The power absorber and inertia flywheels, which simulate the road force experienced by a vehicle, are connected to the front roll. This causes a greater tangential force at the tire/front-roll interface than at the rear-roll interface, resulting in a smaller effective rolling radius in the tire with respect to the front roll as opposed to the rear roll.

Externally coupling the rolls eliminates the difference in velocities of the two rolls. Therefore, this has been considered as an alternative method for simulating the vehicle speed. Locating the speed sensor on the front roll has also been suggested, since the forces and the velocity would then be associated with the same surface. To determine which method would best simulate the actual road velocity of a vehicle, a test program was conducted. The following discussion describes the track tests, the dynamometer tests, and the road to dynamometer comparison which were used to determine the optimum method for measuring the simulated velocity of a vehicle.

II. DISCUSSION

The test program consisted of three portions: 1) track portion 2) dynamometer portion, and 3) data analysis. The track portion was conducted at the Transportation Research Center of Ohio (TRC). The dynamometer portion was conducted at the EPA laboratory in Ann Arbor. One vehicle, a 1978 Mercury Montego, was used for all testing. Steady-state tests were conducted on both the track and the dynamometer, for four different sets of radial tires which are listed in Appendix A-1.

A. Track Portion

Prior to each test, the vehicle was weighed with a full tank of indolene test fuel, complete instrumentation, and two operators. After a 20-minute warm up at 50 mph around an oval track, data were collected during one lap of the track for approximately 10 minutes at steady state 50 mph. Both left and right rear wheel speeds, left and right rear wheel torques, and a fifth wheel speed were recorded at a once/second rate. Total fuel flow and distance traveled were also measured. Ambient temperature, barometric pressure, wind velocity and wind direction were monitored during the tests. Tire temperatures were recorded before and after each test. Immediately following the steady state test, 10 coastdowns were conducted in accordance with the EPA recommended practice for determination of road load for light-duty vehicles. A detailed description of all the equipment used is given in Appendix A-2.

B. Dynamometer Portion

The goal was to reproduce the exact road torque and speed conditions for each test on the dynamometer. In order to obtain the necessary precision, we instead chose to use a 9-point speed/torque test matrix, and then to interpolate the dynamometer data to the road datum.

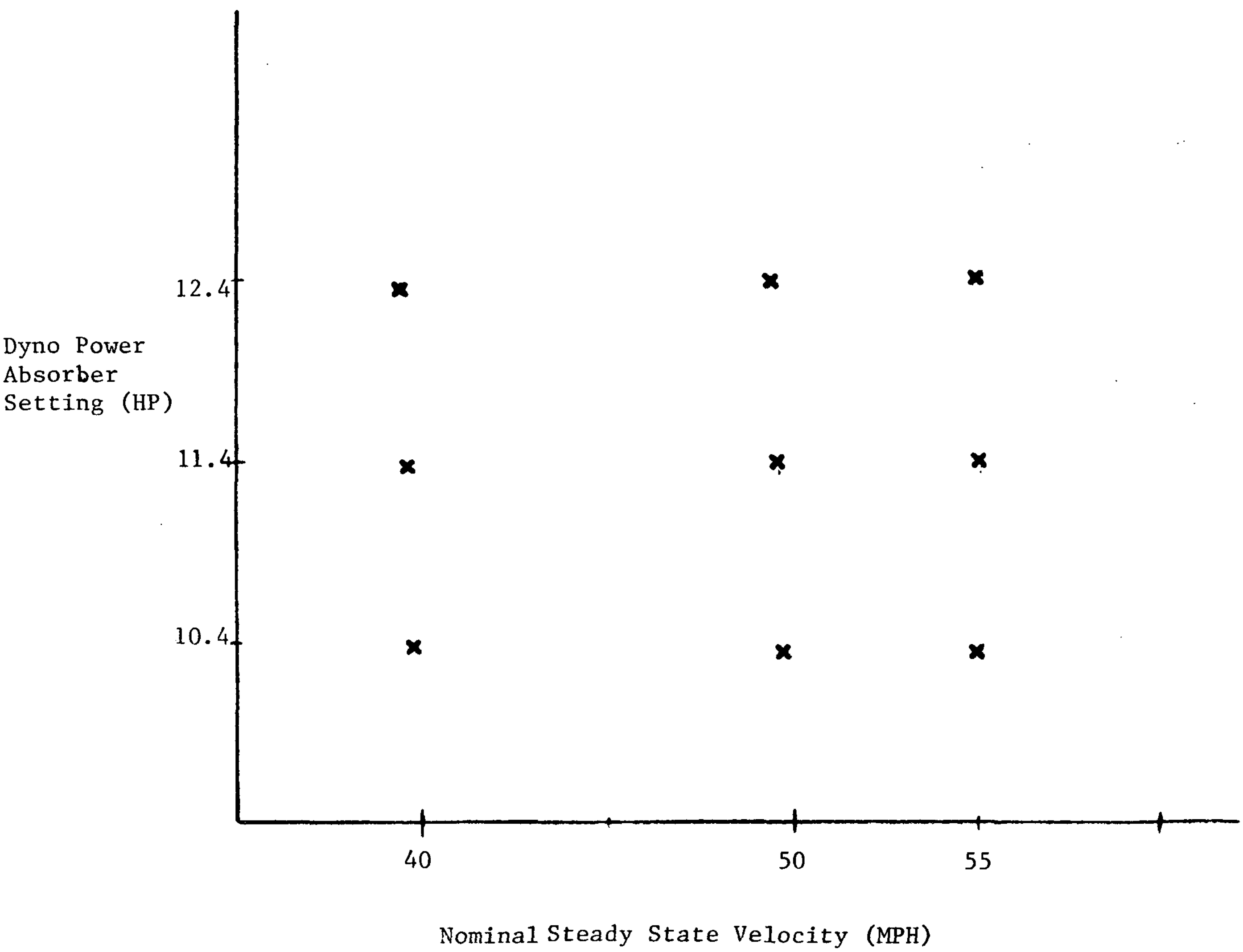
For the dynamometer tests, it was decided to warm-up the tires so that they would be at approximately the same conditions as are vehicle tires during typical EPA tests. This was chosen since the results would be more representative of conditions during EPA tests than would result from a 20 minute 50 mph steady-state warm-up and there would be reduced probability of tire failures. This approach also resulted in tire temperatures which were closer to the road tire temperatures than would have occurred with the 20 minute steady-state warm-up.

The test cycle chosen consisted of a tire warm-up of one complete FTP cycle followed by three consecutive 5 minute steady-state measurements at a single horsepower. At this time a 15 minute cool down period was provided before the dynamometer adjustment was changed, then the first 505 seconds (bag one) of the LA4 cycle was driven to precondition the tires and three more steady-state measurements were obtained. This cycle of a cool down followed by a preconditioning was repeated until all data necessary for the 9 point matrix were obtained. The 15 minute cool down followed by the 505 seconds of preconditioning was chosen on the basis of tire temperature measurements, to be appropriate to yield approximately the same tire temperatures as were obtained after one complete LA-4 cycle starting with a cold tire. No tire failures were observed in this program, either as a result of the warm-up cycle or the measurement conditions.

The vehicle was tested with each set of tires at three steady-state speeds, nominally: 1) 50 mph, 2) 40 mph, and 3) 55 mph. For greater precision the actual measured velocities were used in the data analysis. The 55 mph point was chosen instead of 60 mph since, at 60 mph the tire temperature increased rapidly, indicating possible tire failure problems. Data were collected during each steady state test for 5 minutes at a once/second rate. As in the track portion, both rear-wheel torques and rear-wheel speeds were recorded. Instead of a fifth wheel speed, the front and rear dynamometer roll speeds were recorded. Fuel flow and rear roll distance traveled were also measured. Each steady state was followed by a vehicle/dynamometer coastdown from 55 mph to 45 mph and the coastdown time was recorded. The dynamometer coastdown times were only used for a fuel economy comparison as described in Section III. The steady-states and the coastdowns were repeated at each speed for three different indicated dynamometer power absorber settings: 1) 11.4 HP, 2) 12.4 HP, 3) 10.4 HP, in that order. This test sequence is summarized in the 9-point test matrix shown in Figure 1. The 11.4 HP value

Figure 1

Dynamometer Test Matrix



approximately represented the road load of the vehicle, with the midrange set of tires, as determined by matching the road and dynamometer coast-down times. The 10.4 and 12.4 test values were chosen to cover the range of road loads, observed with different tires. For greater precision, actual wheel torques and wheel speeds were used to match the dynamometer test to the road. This was done by a linear regression which is described in Section IIC.

The entire configuration was then repeated, for each tire set, with the front and rear rolls coupled by a motorcycle chain, and sprockets connected to each roll. A detailed description of the test sequence including warm-up cycles for the dyno portion is given in Appendix B. All the equipment used in the dyno portion was the same as the equipment used in the track portion with the exception of replacement of some minor damaged components and the additional equipment associated with the dynamometer. These are included in the equipment list of Appendix A-2.

C. <u>Data Analysis for Road to Dynamometer Comparisons</u>

For each set of tires, one 50 mph steady-state test was conducted on the road. For each test, mean rear wheel angular speeds, mean rear wheel torques, and a mean fifth wheel speed were calculated.

Conceptually, the intent was to reproduce the rear wheel torque and speed conditions of the vehicle which were observed on the road, for each set of tires on the dynamometer. Under these conditions, the different possible speed measurements would be sampled, and that method of measurement which best agreed with the road fifth wheel velocity would be selected as the most appropriate method of measuring the dynamometer simulated speed.

The conceptual approach could not be used directly because of the experimental precision considered necessary to resolve the small velocity variations among the different methods of dynamometer speed simulation. Therefore, we chose to use the 9-point steady-state speed/torque test matrix described in Figure 1.

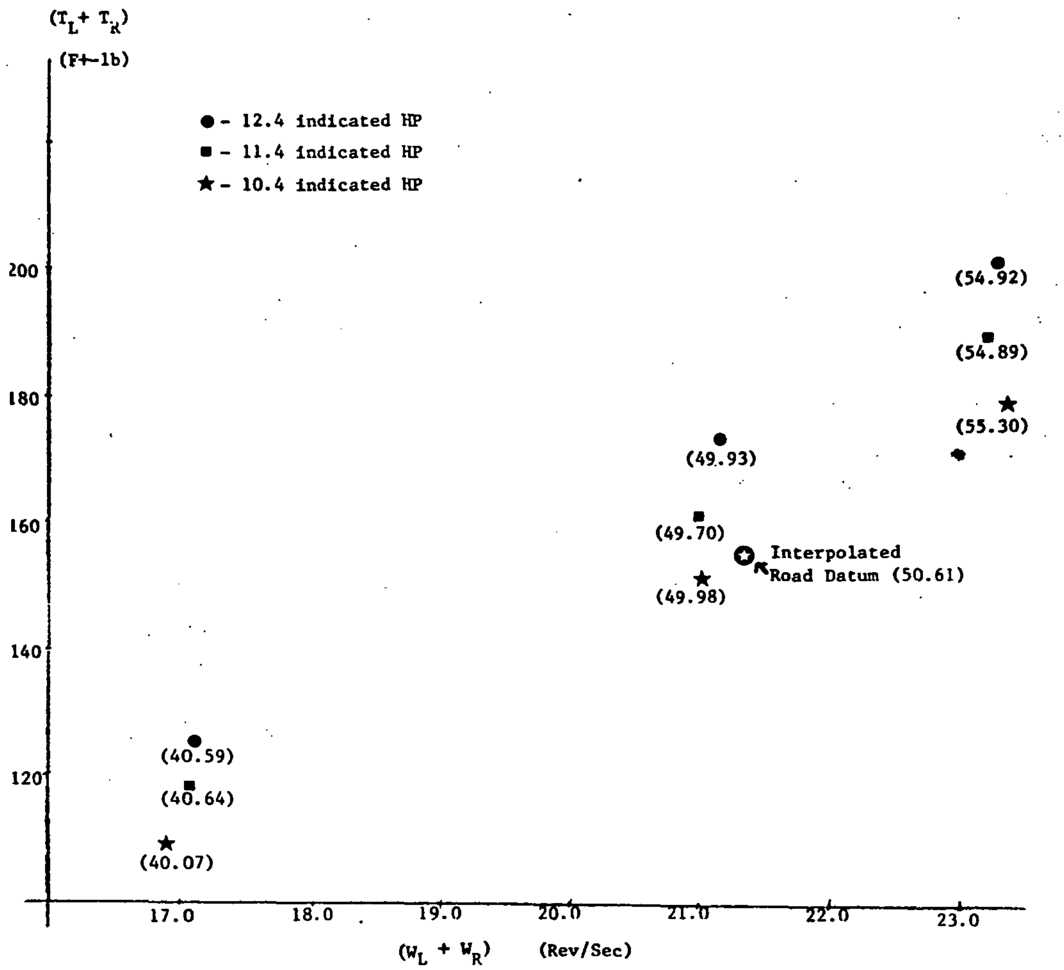
The data obtained at these points uses the interpolated velocity to obtain a roll velocity corresponding to the conditions observed during the road tests. The interpolation was conducted by means of a multiple linear regression using the mean of the data at each point of the test matrix.

First, as discussed, the mean values of each rear wheel angular speed, each rear wheel torque, and each dynamometer roll velocity, with rolls coupled and uncoupled was calculated for every steady-state test. An example of these data for one of the nine point matrices is graphically shown in Figure 2. The interpolation of these data to the observed road point was accomplished by regressing each roll velocity versus the sum of the mean rear wheel angular speeds and the sum of the mean rear wheel torques, over each 9-point test matrix, yielding the coefficients for the following equations:

Figure 2

Tire 4 With Rolls Coupled

Sum of the Rear Wheel Torques vs. Sum of the Rear Wheel Angular Speeds



*The values in parenthesis under each point are the rear roll velocities in (MPH)

$$\bar{V}_{RR} = a_R(\bar{W}_L + \bar{W}_R) + b_R(\bar{T}_L + \bar{T}_R) + C_R \quad (1)$$

$$\bar{V}_{FR} = a_F(\bar{W}_L + \bar{W}_R) + b_F(\bar{T}_L + \bar{T}_R) + C_F \quad (2)$$

$$\bar{V}_{coup} = a_C(\bar{W}_L + \bar{W}_R) + b_C(\bar{T}_L + \bar{T}_R) + C_C \quad (3)$$

Where:

$\bar{V}_{RR}$ = mean rear roll velocity

$\bar{V}_{FR}$ = mean front roll velocity

$\bar{V}_{coup}$ = mean rear roll velocity with rolls coupled

$\bar{W}_L$ = mean left wheel angular speed

$\bar{W}_R$ = mean right wheel angular speed

$\bar{T}_L$ = mean left wheel torque

$\bar{T}_R$ = mean right wheel torque

a's, b's, c's = unique sets of regression coefficients for each roll condition and each 9-point test matrix

The road values of mean wheel torques and speeds were inserted into equations (1), (2), and (3) for each set of tires to obtain the simulated road velocity for each method of speed measurement interpolated to the road conditions. The predicted road velocities as given by the above equations, were then compared to the actual mean road velocity for the same set of tires:

$$V_{RR/Road} = a_R(\bar{W}_L + \bar{W}_R)_{Road} + b_R(\bar{T}_L + \bar{T}_R)_{Road} + C_R$$

$$V_{FR/Road} = a_F(\bar{W}_L + \bar{W}_R)_{Road} + b_F(\bar{T}_L + \bar{T}_R)_{Road} + C_F$$

$$V_{coup/Road} = a_C(\bar{W}_L + \bar{W}_R)_{Road} + b_C(\bar{T}_C + \bar{T}_R)_{Road} + c_C$$

Where:

$V_{RR/Road}$ = Road velocity as simulated by the rear roll at the road conditions

$V_{FR/Road}$ = Road velocity as simulated by the front roll at the road conditions

$V_{coup/Road}$ = Road velocity as simulated with the rolls coupled

a,b,c = the set of coefficients obtained from the regressions of the dynamometer data for each tire (different for the rear roll, front roll, and coupled roll predictions)

Sample calculations and the original data, including the regression coefficients are given in appendix C.

III. RESULTS

The results of all tests on the radial and bias belted tires are given in Table 1.

The mean deviation from the actual road velocity for the radial tires was +1.10% using the rear roll velocity simulation, -1.07% using the front roll, and -0.22% with the rolls coupled. Where, a positive deviation corresponds to an observed dynamometer velocity greater than the road velocity under the same wheel condition.

For the bias-belted tires, the rear roll deviated by +1.23% from the road, the front roll deviated by -0.04%, and the coupled rolls deviated by +0.40%.

Overall, the rear roll was in error by +1.15%, the front roll by -0.71%, while the error with the rolls coupled was only -0.02%. Therefore, on the average and particularly for radial tires the coupled mode most closely simulated the road.

Since coupling the rolls improved the vehicle velocity simulation, the vehicle fuel economy effect of this change was investigated. In the majority of EPA fuel economy tests, alternate dynamometer adjustments, obtained by the coastdown technique, are used. Also the coastdown method is used in dynamometer calibration, and therefore, would account for the increased friction of the coupling mechanism. Consequently, a comparison of vehicle fuel economy, obtained with dynamometer adjustments, which produced equal coastdown times, was considered the most appropriate approach to evaluate the fuel economy effect of coupling the dynamometer rolls. This comparison could easily be made since, during the dynamometer portion of this test program, vehicle dynamometer coastdown times were recorded immediately following the fuel consumption tests.

Figure 3 shows the 50 MPH fuel consumption of the vehicle, equipped with radial tires, plotted versus the coastdown time obtained for both the uncoupled and coupled tests. This plot indicates that coupling the dynamometer rolls results in a 2 to 6 percent increase in measured fuel consumption for the same vehicle-dynamometer coastdown time. For example, at a coastdown time of 14.0 sec, the fuel consumption was approximately 7150 cc/km with the rolls uncoupled and about 7450 cc/km with the rolls coupled, a difference of approximately 4%.

The fuel economy results obtained in this test program are all from steady-state measurements. However, the results are consistent are preliminary investigations of the effect on transient cycles. For example, computer modeling has estimated the transient cycle fuel economy effect to be about 4%.(2) Limited empirical data from transient cycle tests also indicate the effect to be about 4%.(3)

IV. CONCLUSIONS

Operating with the rolls coupled most closely simulates the road experience of a vehicle using radial tires, and therefore, provides the most accurate method of testing for fuel economy. The current EPA method for simulating the vehicle velocity, using the rear roll speed, causes an over prediction of steady-state 50 mph fuel economy by approximately 4%. This occurs because the velocity error results in both an underloading of the energy demand from the vehicle and an overcredit of the distance travelled.

The same mechanism occurs during transient cycles and in this instance, inertial forces applied to the vehicle are also inappropriately low because of the velocity error. Computer modeling and limited empirical data indicate the transient cycle fuel economy errors resulting from this velocity error are also about 4%. It should be noted that these conclusions are based on data from vehicles equipped with radial tires, however this is the most important case. It is estimated that over 70% of the vehicles tested at EPA are equipped with radial tires.

Table 1

Radial Tires

Tire No.	Road Velocity Predicted by the Front Roll (mph)	Road Velocity Predicted by the Rear Roll (mph)	Road Velocity Predicted with Rolls Coupled (mph)	Observed Road Velocity (mph)
1	50.05	51.19	50.45	50.81
2	49.72	50.58	50.00	50.10
3	50.18	51.43	50.85	50.83
4	50.26	51.38	50.61	50.62
Mean	50.05	51.15	50.48	50.59
% Deviation	-1.07	+1.10	-0.22	-

$$\left(\frac{\text{Predicted - Observed}}{\text{Observed}}\right) \times 100$$

Bias Belted Tires

Tire No.	Road Velocity Predicted by the Front Roll (mph)	Road Velocity Predicted by the Rear Roll (mph)	Road Velocity Predicted with Rolls Coupled (mph)	Observed Road Velocity (mph)
6	50.53	51.16	50.82	50.51
7	50.55	51.20	50.70	50.60
Mean	50.54	51.18	50.76	50.56
% Deviation	-0.04	+1.23	+0.40	-

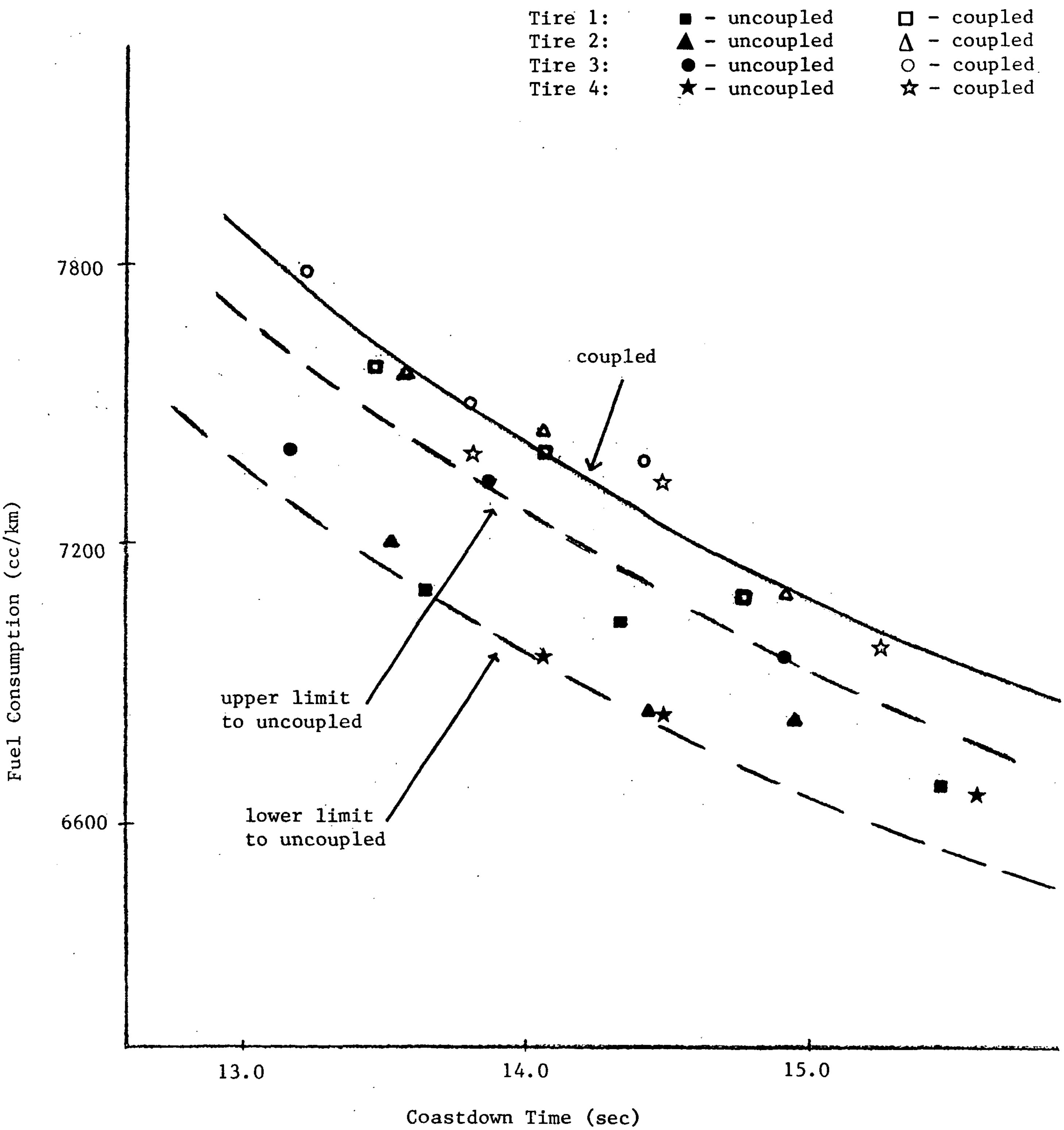
TOTALS

	Road Velocity Predicted by the Front Roll (mph)	Road Velocity Predicted by the Rear Roll (mph)	Road Velocity Predicted with Rolls Coupled (mph)	Observed Road Velocity (mph)
Mean	50.22	51.16	50.57	50.58
% Deviation	-0.71	+1.15	-0.02	-

Error analysis indicated that on the average, we were 95% confident that the predicted values were accurate to within $\pm$0.23 mph.

Figure 3

Coupled vs Uncoupled Fuel Consumption
Plotted Against Coastdown Time
(with radial tires)



References

1. Richard Burgeson, Myriam Torres, "Tire Slip on the Clayton Dynamometer", EPA Technical Support Report, LDTP 78-02, March 1978.

2. John Yurko, "Computer Simulation of Tire Slip on a Clayton Twin Roll Dynamometer", EPA Technical Support Report, SDSB 79-10, February 1979.

3. Conversation with Don Paulsell, of the EPA Ann Arbor Laboratory, March 1979.

Appendix A-1

Tire No.	Tire	Tire Type	Tire Size
1	Michelin-X	Radial	GR78x15
2	Firestone 721	Radial	GR78x15
3	Firestone 721	Radial	GR78x14
4	Multimile Supreme	Radial	GR78x15
6	Uniroyal Fastrak	Bias Belted	G78x15
7	Uniroyal Fastrak	Bias Belted	G78x15

Vehicle

1976 Mercury Montego w/ 29,000 accum. miles

Appendix A-2

Type of Data Being Collected	Equipment
Drive wheel torques (analog voltage output)	Lebow torque sensor Model No. - 7510
Wheel angular velocities (frequency output)	Disc/Rotaswitch pulse Encoders
Conversion of frequency to analog voltage	Anadex frequency to voltage converter
Collect and digitize analog signals for output to a recording device	Fluke datalogger Model 2240B
Record data	Techtran Data Cassette Model 8400
Record fuel flow	Fluidyne Flowmeter Model 1250T
Tire temperatures	Wahl Heat Spy Infared thermometer

Appendix B

OVERVIEW OF TEST SEQUENCE
(eg. using tire no. 3)

1. Tire no. 3 mounted, pressure set to 45 PSI.

2. Tires broken in with 1 FTP.

3. Allowed to cool at least 4 hours.

4. Reset pressure to 45 PSI.

5. Vehicle rear axle weight approximately 2290 lb with driver and full gas tank.

6. Set dynamometer inertia to 5000 lbs.

7. Set dynamometer horsepower to 11.4 horsepower.

8. Set fixed data to 350114.

9. Conduct 1 FTP, then obtain tire temperatures.

10. Insert tape in techtran, ready for scan at 1 second intervals (Tape labeled: uncoupled 350114, 3501124).

11. Conduct a 5-minute Steady State at 50 mph, collect data.

12. Conduct a coastdown, collect 55 to 45 mph time only.

13. Record tire temperature during or right after coastdown, reset fixed data to 340114.

14. Conduct a 5-minute Steady State at 40 mph, collect data.

15. Conduct a coastdown. (NOTE: be sure to collect data only during the 5-minute Steady State. All data collection devices should be reset before new Steady State speed is set.) Collect coastdown time and tire temperatures.

16 Reset fixed data to 355114, conduct a Steady State at 55 mph for 5 minutes collecting data. Stop data, conduct a coastdown, record time and tire temperatures. Increase speed above 60 mph.

17. Life vehicle, conduct a <u>dynamometer only</u> coastdown, check zero, adjust on torque meter. Record 55 to 45 mph time. Reset horsepower to 12.4, fixed data to 350124. Tires should be allowed to cool 15 minutes starting from when the vehicle was lifted.

Appendix B (cont.)

18. Conduct a 505 second warm up, record tire temperature.

19. Repeat 11 and 12.

20. Reset fixed data to 340124.

21. Repeat 14 and 15.

22. Reset fixed data to 355124.

23. Repeat 16.

24. Repeat 17. Reset horsepower to 10.4 after dynamometer coastdown, fixed data to 350104, allow 15 minutes cooling, rewind tape and insert new one. (Tape labeled: Uncoupled, 350104).

25. Conduct a 505 second warm up, repeat 11 and 12.

26. Reset fixed data to 340104.

27. Repeat 14 and 15.

28. Reset fixed data to 355104.

29. Repeat 16.

30. Conduct dynamometer only coastdown, recheck zero drift. Rewind tape.

31. Steps 1 through 30 complete a tire for the uncoupled configurations. Approximately 3 to 4 hours of testing and 2 cassette tapes are required. If nothing is done to the vehicle but to let it set for an hour (say for lunch), you should be able to start at step 6 with rolls coupled and fuel tank filled, and conduct steps 6 through 30 to complete a tire type.

    Steps 1 through 31 will be repeated for each tire set.

Appendix C-1

Tire 3
9-Point Test Matrix Data on Dynamometer
with Rolls Uncoupled

Test	$\overline{RRV}$ (mph)	$\overline{FRV}$ (mph)	$(\bar{W}_L+\bar{W}_R)$ (rev/sec)	$(\bar{T}_L+\bar{T}_R)$ (ft.-lbs.)
350114	50.116	49.170	21.598	155.892
340114	39.979	39.423	17.239	120.743
355114	55.125	53.932	23.672	181.191
350124	49.955	48.556	21.402	167.662
340124	40.091	39.183	17.198	125.286
355124	55.074	53.421	23.508	187.087
350104	50.068	48.857	21.415	149.114
340104	40.166	39.375	17.181	112.087
355104	54.881	53.459	23.426	164.744
		With Rolls Coupled		
351114	50.031	50.075	21.710	178.241
341114	40.109	40.130	17.340	138.261
356114	55.030	55.084	23.941	206.123
351124	49.870	49.902	21.618	177.924
341124	39.936	39.948	17.306	131.293
356124	55.011	55.045	23.894	202.540
351104	49.990	50.041	21.678	159.231
341104	40.029	40.040	17.312	118.504
356104	55.031	55.079	23.821	183.033

Regression Coefficients
$(Vi = a\ (W_L + W_R) + b\ (T_L + T_R) + C)$

Vi	a	$b \times 10^2$	C	R-SQR
Rear Roll	2.3808	-0.26600	-0.58549	.99934
Front Roll	2.3639	-1.2120	-0.078181	.99991
Coupled Roll	2.3320	-0.46453	+0.23591	.99991

$(W_L + W_R)$ road = 22.03 rev/sec and $(T_R + T_L)$ road = 162.98 ft.-lb

(R-SQR signifies the confidence in the fit of the regression. For example, R-SQR = .99991 means a 99.991% confidence in the fit.)

Appendix C-2

Example Calculation Using Tire 3
<u>Rear Roll Velocity with the Rolls Coupled</u>

$$V_{coup} = a\ (\bar{W}_L + \bar{W}_R) + b\ (\bar{T}_L + \bar{T}_R) + C$$

from linear regression with $\overline{RRV}$ from appendix C-1 as the dependent variable: :

$$a = 2.3320,\ b = -0.46453 \times 10^{-2},\ c=0.23591$$

therefore, applying the coefficients to the road data results:

$$V_{coup/road} = 2.3320\ (\bar{W}_L + \bar{W}_R)\ \text{road} + -0.46453 \times 10^{-2}\ (\bar{T}_L + \bar{T}_R)\ \text{road} + 0.23591$$

where:

$$(\bar{W}_L + \bar{W}_R)\ \text{road} = 22.03, \text{ and } (\bar{T}_R + \bar{T}_L)\ \text{road} = 162.98$$

therefore:

$$V_{coup/road} = 50.85$$

this compares to the actual road velocity:

$$V_{road} = 50.83$$

(These correspond to the results given in Table 1. Section III of this report.)

Appendix C-3

Tire 1
9-Point Test Matrix on Dynamometer
with Rolls Uncoupled

Test	$\overline{RRV}$ (mph)	$\overline{FRV}$ (mph)	$(\bar{W}_L + \bar{W}_R)$ (rev / sec)	$(\bar{T}_L + \bar{T}_R)$ (ft. - lbs.)
150114	50.073	49.995	20.902	165.847
140114	40.002	39.340	16.690	127.049
155114	54.950	53.651	22.893	188.137
150124	50.001	48.694	20.800	167.585
140124	40.019	39.163	16.643	122.969
155124	54.982	53.488	22.848	187.133
150104	49.971	48.865	20.782	146.920
140104	39.946	39.218	16.618	111.007
155104	55.021	53.681	22.849	168.222

with Rolls Coupled

151114	50.044	50.100	21.164	181.263
141114	39.983	40.006	16.828	150.630
156114	54.937	55.042	23.239	205.630
151124	50.032	50.071	21.139	175.900
141124	40.058	40.066	16.861	128.142
156124	55.088	55.125	23.278	210.694
151104	49.927	49.963	21.068	158.839
141104	40.035	40.042	16.829	114.663
156104	54.945	54.998	23.175	180.070

Regression Coefficients

Vi	a	$b \times 10^2$	c	R-SQR
Rear Roll	2.4586	-0.48606	-0.37559	.99988
Front Roll	2.3336	-0.10248	-0.56480	.99750
Coupled Roll	2.3689	-0.29440	0.50768	.99996

$(\bar{W}_L + \bar{W}_R)$ road = 21.27, and $(\bar{T}_L + \bar{T}_R)$ road = (150.616)

(R-SQR signifies the confidence in fit of the data by the regression)

Appendix C-4

Tire 4
9- Point Test Matrix on Dynamometer with Rolls Uncoupled

Test	$\overline{RRV}$ (mph)	$\overline{FRV}$ (mph)	$(\bar{W}_L + \bar{W}_R)$ (rev / sec)	$(\bar{T}_L + \bar{T}_R)$ (ft. - lbs)
450114	49.960	48.951	20.864	152.446
440114	39.968	39.374	16.623	115.488
455114	55.013	53.765	22.849	176.968
450124	49.990	48.780	20.786	156.114
440124	40.007	39.238	16.591	114.620
455124	55.120	53.680	22.849	178.410
450104	49.956	48.907	20.754	142.134
440104	39.952	39.287	16.575	107.053
455104	55.054	53.873	22.856	165.278

with Rolls Coupled

Test	$\overline{RRV}$ (mph)	$\overline{FRV}$ (mph)	$(\bar{W}_L + \bar{W}_R)$ (rev / sec)	$(\bar{T}_L + \bar{T}_R)$ (ft. - lbs)
451114	49.697	49.847	20.999	160.798
441114	40.636	40.733	17.021	119.410
456114	54.887	55.113	23.223	189.825
451124	49.929	50.084	21.154	173.993
441124	40.589	40.688	17.048	125.797
456124	54.918	55.084	23.268	200.720
451104	49.983	50.126	21.086	151.774
441104	40.074	40.175	16.810	109.630
456104	55.295	55.484	23.359	175.490

Regression Coefficients

Vi	a	$b \times 10^2$	c	R-SQR
Rear roll	2.3939	0.12847	0.071297	.99973
Front roll	2.3838	-0.78016	0.57721	.99977
Coupled roll	2.3781	-0.64562	0.84438	.99992

$(\bar{W}_L + \bar{W}_R)$ road = 21.35 and $(\bar{T}_L + \bar{T}_R)$ road = 155.603

Appendix C-5

Tire 2
9- Point Test Matrix Data on Dynamometer
with Rolls Uncoupled

Test	$\overline{RRV}$ (mph)	$\overline{FRV}$ (mph)	$(\bar{W}_L + \bar{W}_R)$ (rev / sec)	$(\bar{T}_L + \bar{T}_R)$ (ft. - lbs)
250114	49.880	48.803	20.916	159.274
240114	39.949	39.251	16.773	123.905
255114	54.976	53.764	22.994	182.863
250124	49.921	49.108	20.980	165.863
240124	40.014	39.561	16.863	123.553
255124	55.061	54.018	23.037	189.958
250104	49.945	49.237	21.036	147.109
240104	39.887	39.492	16.820	108.334
255104	55.121	54.222	23.209	165.357

with Rolls Coupled

Test	$\overline{RRV}$ (mph)	$\overline{FRV}$ (mph)	$(\bar{W}_L + \bar{W}_R)$ (rev / sec)	$(\bar{T}_L + \bar{T}_R)$ (ft. - lbs)
251114	50.197	50.340	21.404	174.465
241114	40.167	40.251	17.071	130.972
256114	55.121	55.290	23.511	198.727
251124	50.009	50.132	21.347	172.235
241124	39.980	40.056	16.993	124.866
256124	54.958	55.139	23.455	197.955
251104	49.925	50.061	21.243	161.941
241104	40.111	40.194	17.025	123.351
256104	55.061	55.218	23.437	186.192

Regression Coefficients

Vi	a	$b \times 10^2$	c	R-SQR
Rear roll	2.3000	1.1332	-0.085243	.99987
Front roll	2.3081	0.17002	0.40039	.99984
Coupled roll	2.4186	-0.91726	0.045152	.99996

Appendix C-6

Tire 7
9-Point Test Matrix Data on Dynamometer
with Rolls Uncoupled

Test	$\overline{RRV}$ (mph)	$\overline{FRV}$ (mph)	$(\bar{W}_L + \bar{W}_R)$ (rev / sec)	$(\bar{T}_L + \bar{T}_R)$ (ft. - lbs)
750114	49.996	49.435	21.102	154.821
740114	39.878	39.562	16.891	114.676
755114	55.081	54.341	23.189	178.088
750124	50.054	49.396	21.114	156.746
740124	39.947	39.576	16.915	112.423
755124	54.917	54.065	23.090	177.521
750104	50.108	49.549	21.136	142.726
740104	40.084	39.773	16.994	106.785
755104	55.158	54.473	23.312	165.109
		with Rolls Coupled		
751114	50.123	50.281	21.368	166.150
741114	39.894	39.994	17.040	121.278
756114	55.142	55.391	23.513	191.962
751124	50.028	50.168	21.333	167.352
741124	40.034	40.117	17.101	118.877
756124	54.957	55.104	23.415	191.912
751104	49.947	50.100	21.289	157.123
741104	40.041	40.131	17.102	113.344
756104	54.966	55.129	23.372	177.934

Regression Coefficients

Vi	a	$b \times 10^2$	c	R-SQR
Rear roll	2.3246	0.84300	-0.32574	.99992
Front roll	2.3209	0.20201	0.12043	.99994
Coupled roll	2.4311	-0.59811	-0.83437	.99998

$(\bar{W}_L + \bar{W}_R)$ road = 21.59 and $(\bar{T}_R + \bar{T}_L)$ road = 159.165

Appendix C-7

Tire 6
9-Point Test Matrix Data on Dynamometer
with Rolls Uncoupled

Test	$\overline{RRV}$ (mph)	$\overline{FRV}$ (mph)	$(\bar{W}_L + \bar{W}_R)$ (rev / sec)	$(\bar{T}_L + \bar{T}_R)$ (ft. - lbs)
650114	50.078	49.485	20.599	160.995
640114	40.077	39.786	16.552	119.909
655114	54.923	54.293	22.551	184.427
650124	50.029	49.440	20.537	161.376
640124	40.036	39.712	16.527	117.758
655124	55.033	54.272	22.574	184.391
650104	50.133	49.597	20.624	153.316
640104	39.972	39.665	16.483	113.553
655104	54.979	54.303	22.519	172.812

with Rolls Coupled

651114	49.979	50.137	20.736	168.248
641114	40.078	40.179	16.623	122.804
656114	55.094	55.271	22.716	194.150
651124	50.004	50.167	20.738	182.684
641124	39.860	39.960	16.526	135.170
656124	55.095	55.268	22.793	210.181
651104	50.082	50.223	20.593	157.842
640104	40.094	40.187	16.606	115.606
656104	54.939	55.215	22.745	180.082

Regression Coefficients

Vi	a	$b \times 10^2$	c	R-SQR
Rear roll	2.5062	-0.24795	-1.0851	.99995
Front roll	2.4694	-0.50356	-0.48771	.99996
Coupled roll	2.4904	-0.46889	-0.70698	.99960

$(W_L + W_R)$ road = 21.0166 and $(T_L + T_R)$ road = 173.9324

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