LDTP 78-09

Technical Report

Clayton Dynamometer-to-Road Tire Rolling Resistance Relationship

by

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NOTICE

Technical reports are intended to present a technical analysis of an issue and recommendations resulting from the assumptions and constraints or data received subsequent to the date of release of this report may alter the conclusions reached. Readers are cautioned to seek the latest analysis from EPA before using the information contained herein.

Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air and Waste Management
U.S. Environmental Protection Agency

I. Introduction

Currently, EPA emissions and fuel economy testing is conducted on the twin small-roll Clayton Dynamometer. It has long been assumed that two tires at 45 PSI operated on the Clayton Dynamometer are equivalent to four tires at 26 PSI operated on the road. This assumption was examined in an EPA report entitled "Tire-Dynamometer Roll Effects." That report (1) presents tire rolling resistance data collected on both a Clayton Dynamometer and a single large-roll (48" diameter) dynamometer. The tires tested had a cold inflation pressure of 45 PSIG. The data generated on the single large-roll dynamometer were then corrected for roll curvature and to an inflation pressure of 26 PSI. The relationship between these corrected data and the 45 PSIG Clayton data was then investigated.

A recently completed EPA study to determine the effects of tire inflation pressure on tire rolling resistance (2) as measured on the single large-roll dynamometer indicated that the inflation pressure correction factor utilized in the previous study was too large. The previous report (1) utilized a factor of 3% decrease in tire rolling resistance for each 1 PSI inflation pressure increase. The later study indicated that the effect was, in general, 2.21% decrease per PSI increase. This study also indicated that the magnitude of the effect was dependent on tire type and size.

This report compares the rolling resistance data at 45 PSI as measured on the Clayton Dynamometer from the previous study with the recently obtained tire rolling resistance data at 26 PSI as measured on the single large-roll dynamometer and corrected for roll curvature.

II. Program Design

Tire rolling resistance data generated during the two previous studies were combined for statistical analysis. Data collected on tires at an inflation pressure of 45 PSI on the Clayton Dynamometer were compared with data collected on the same tires at an inflation pressure of 26 PSI on a single large-roll dynamometer. The 26 PSI data were corrected for roll curvature prior to data analysis so that the assumption of "two tires at 45 PSI on the Clayton Dynamometer are equivalent to four tires at 26 PSI on the road" could be re-examined. Appendix A presents these data.

III. Analysis

The methodology used to determine the tire rolling resistance, F_{RR} and the amount of power absorbed by the tire at 50 MPH, P_{ATN}, was the same as that reported by the two previous EPA studies (1), (2). The roll curvature correction was also the same.

As a method of comparison between this two data sets, the ratios of the mean values for F_{RR} and P_{ATN} were computed according to the following equation by tire type:

$$R_{CR} = \frac{\text{Mean } F_{RR}\text{* Clayton (45 PSI)}}{\text{Mean } F_{RR}\text{* Road (26 PSI)}}$$

*The respective mean values for P_{ATN} may be substituted for F_{RR} when computing R_{CR}.

The parameter R_{CR} is the ratio of the mean Clayton results to the mean road results and is identical to R_{CE} reported in (1). Ideally, if the basic assumption is correct, R_{CE} R_{CR} should be equal to a value of "2.0".

The resulting computations again (1) indicate that the basic assumption is incorrect. Tables 1 and 2 present the values of R_{CR} and the previously reported prediction values of R_{CE}, respectively, for each tire type tested.

Table 1

Clayton-To-Road Relationship, R_{CR}, By Tire Type

Tire Type	Clayton (45 PSI) P_{ATN} (watts)	Clayton (45 PSI) F_{RR} (lb/k-lb)	Large Roll (26 PSI) Corrected to Road P_{ATN} (watts)	Large Roll (26 PSI) Corrected to Road F_{RR} (lb/k-lb)	(Actual) R_{CR}
Radial	5721.960	19.282	3099.300	10.440	1.85
Bias	5212.867	17.567	3758.600	12.661	1.39
Belted Bias	5829.297	19.644	3917.700	13.197	1.49

Table 2

Predicted Clayton-To-Road Relationship, R_{CE}, By Tire Type

Tire Type	Clayton (45 PSI) P_{ATN} (watts)	Clayton (45 PSI) F_{RR} (lb/k-lb)	Large Roll-Corrected To Road and 26 PSI P_{ATN} (watts)	Large Roll-Corrected To Road and 26 PSI F_{RR} (lb/k-lb)	(Predicted) R_{CR}
Radial	5721.960	19.282	3404.091	11.470	1.68
Bias	5212.867	17.567	3997.113	13.469	1.30
Belted Bias	5829.297	19.644	5086.178	17.138	1.15

It should be noted that as the tire inflation pressure on the road increases, the rolling resistance decreases and R_{CR} approaches "2.0". Based on the effects of tire pressure on tire rolling resistance information reported in (2), road tire pressures of 29.6, 43.5, and 57.1 PSI for radial, bias belted and bias ply tires, respectively, would be required to produce a value of "2.0" for R_{CR}. These predictions assume that the effect of tire pressure on rolling resistance is linear. The predicted road pressure for radial tires is reasonable, however, the predictions for bias belted and bias ply tires are well beyond the maximum inflation pressure for passenger car tires. In addition, the extrapolation of the inflation pressure effect beyond 45 PSI may not be accurate, since data beyond 45 PSI were not included in the data base, and a linear relationship would not be expected at high inflation pressures.

The current trend on the part of the automobile manufacturer to obtain fuel economy improvements is to lower tire rolling resistance by recommending increased inflation pressures. In addition, radial tires are used extensively on vehicles submitted for EPA certification so it would appear that for most vehicles the assumption of "two tires at 45 PSI on the Clayton are equivalent to four tires on the road" is valid. Of course, the assumption only holds for vehicles with tire inflation pressures of approximately 30 PSI.

IV. Conclusions

Based on the data present, the following conclusions may be drawn:

1) For vehicles equipped with radial tires inflated to pressures of approximately 30 PSI, two tires at 45 PSI on the Clayton are equivalent to four tires (at 30 PSI) on the road.

2) The Clayton Dynamometer under loads vehicles equipped with bias belted and bias ply tires. The current light-duty vehicle road load equation provides for vehicles with bias ply tires (belted and non-belted). However, the magnitude of this provision may need correction.

References

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APPENDIX A

Tire Test Data

Table A-1

Twin Small-Roll (Clayton) Dynamometer Test Data
By Tire Identification Number

Tire ID	Tire Size	Tire Type	Test Press (PSI)	Rolling Force (NT)	Rolling Resistance (lb/k-lb)	Power Absorbed at 50 MPH (watts)
020	13	RADIAL	45.0	211.985	15.996	4741.770
020	13	RADIAL	45.0	318.867	24.016	7126.680
020	13	RADIAL	45.0	243.519	18.341	5442.641
060	15	BIASBE	45.0	215.197	16.208	4809.652
060	15	BIASBE	45.0	191.215	14.402	4273.656
070	15	RADIAL	45.0	228.500	17.210	5106.977
080	15	RADIAL	45.0	255.517	19.245	5710.805
080	15	RADIAL	45.0	244.348	18.403	5461.180
128	15	RADIAL	45.0	259.704	19.566	5806.172
128	15	RADIAL	45.0	316.487	23.837	7073.484
13A	15	BIAS	45.0	223.471	16.831	4994.578
13A	15	BIAS	45.0	167.927	12.648	3753.168
13B	15	BIAS	45.0	303.906	22.889	6792.301
16A	15	RADIAL	45.0	286.363	21.568	6400.215
16B	15	RADIAL	45.0	319.058	24.030	7130.945
16B	15	RADIAL	45.0	306.953	23.119	6860.398
180	15	RADIAL	45.0	209.757	15.798	4688.070
200	15	RADIAL	45.0	241.231	18.169	5391.512
200	15	RADIAL	45.0	193.477	14.572	4324.211
210	15	RADIAL	45.0	236.157	17.787	5278.109
220	15	RADIAL	45.0	222.740	16.776	4974.238
230	15	RADIAL	45.0	241.985	18.225	5408.363
230	15	RADIAL	45.0	259.831	19.570	5807.223
240	15	RADIAL	45.0	305.471	23.007	6827.277
240	15	RADIAL	45.0	262.152	19.744	5859.098
250	14	RADIAL	45.0	242.089	18.233	5410.688
250	14	RADIAL	45.0	206.359	15.542	4612.125
250	14	RADIAL	45.0	214.421	16.149	4792.309
260	14	RADIAL	45.0	277.830	20.925	6209.500
260	14	RADIAL	45.0	254.925	19.200	5697.574
270	14	RADIAL	45.0	218.589	16.463	4885.465
270	14	RADIAL	45.0	214.263	16.138	4788.777
290	15	RADIAL	45.0	247.647	18.652	5534.910
300	14	RADIAL	45.0	217.997	16.419	4872.234
300	14	RADIAL	45.0	236.793	17.834	5292.324
300	14	RADIAL	45.0	248.923	18.748	5563.430
310	14	RADIAL	45.0	209.629	15.789	4685.207
310	14	RADIAL	45.0	247.823	18.665	5538.844
310	14	RADIAL	45.0	271.225	20.428	6061.879
320	14	BIASBE	45.0	196.342	14.788	4388.242
320	14	BIASBE	45.0	216.169	16.281	4831.379
320	14	BIASBE	45.0	195.912	14.755	4378.633

Table A-1 (cont.)

Twin Small-Roll (Clayton) Dynamometer Test Data
By Tire Identification Number

Tire ID	Tire Size	Tire Type	Test Press (PSI)	Rolling Force (NT)	Rolling Resistance (lb/k-lb)	Power Absorbed at 50 MPH (watts)
330	14	BIASBE	45.0	246.406	18.558	5507.176
330	14	BIASBE	45.0	250.348	18.855	5595.277
330	14	BIASBE	45.0	227.369	17.125	5081.695
340	14	BIASBE	45.0	278.243	20.956	6218.730
340	14	BIASBE	45.0	276.695	20.840	6184.133
340	14	BIASBE	45.0	271.722	20.465	6072.988
350	13	BIAS	45.0	202.452	15.248	4524.801
350	13	BIAS	45.0	306.732	23.102	6855.453
350	13	BIAS	45.0	251.830	18.967	5628.402
370	13	RADIAL	45.0	292.339	22.018	6533.781
370	13	RADIAL	45.0	375.867	28.309	8400.617
400	15	RADIAL	45.0	266.574	20.077	5957.930
400	15	RADIAL	45.0	253.768	19.113	5671.715
410	13	BIAS	45.0	263.859	19.873	5897.258
410	13	BIAS	45.0	366.373	27.594	8188.441
420	15	RADIAL	45.0	266.534	20.074	5957.035
420	15	RADIAL	45.0	312.521	23.538	6984.844

Table A-2

Single Large-Roll Dynamometer Test
Date By Tire Identification Number

Tire ID	Tire Size	Tire Type	Test Press (PSI)	Roll Curvature Corrected Rolling Force (NT)	Roll Curvature Corrected Rolling Resistance (lb/k-lb)	Roll Curvature Corrected Power Absorbed At 50 MPH (watts)
010	13	RADIAL	26.0	168.758	12.710	3773.056
010	13	RADIAL	26.0	127.225	9.582	2844.448
020	13	RADIAL	26.0	160.040	12.053	3578.123
020	13	RADIAL	26.0	148.301	11.169	3315.658
050	14	RADIAL	26.0	155.534	11.713	3477.388
050	14	RADIAL	26.0	139.638	10.517	3121.982
050	14	RADIAL	26.0	147.472	11.106	3297.140
060	15	BIASBE	26.0	138.558	10.435	3097.850
060	15	BIASBE	26.0	158.935	11.970	3553.406
070	15	RADIAL	26.0	167.034	12.580	3734.509
070	15	RADIAL	26.0	127.985	9.639	2861.453
080	15	RADIAL	26.0	183.487	13.819	4102.344
080	15	RADIAL	26.0	160.619	12.097	3591.068
090	15	RADIAL	26.0	117.221	8.828	2620.785
090	15	RADIAL	26.0	116.880	8.802	2613.170
090	15	RADIAL	26.0	113.666	8.560	2541.318
090	15	RADIAL	26.0	119.564	9.005	2673.164
090	15	RADIAL	26.0	116.356	8.763	2601.468
090	15	RADIAL	26.0	123.370	9.292	2758.268
090	15	RADIAL	26.0	121.770	9.171	2722.488
100	13	BIASBE	26.0	166.355	12.529	3719.303
100	13	BIASBE	26.0	167.074	12.583	3735.400
100	13	BIASBE	26.0	159.178	11.988	3558.873
110	14	BIASBE	26.0	167.858	12.642	3752.904
110	14	BIASBE	26.0	167.898	12.645	3753.802
12A	15	RADIAL	26.0	154.366	11.626	3451.255
12A	15	RADIAL	26.0	129.648	9.764	2898.648
12B	15	RADIAL	26.0	148.336	11.172	3315.467
12B	15	RADIAL	26.0	152.762	11.505	3415.398
13A	15	BIAS	26.0	161.487	12.162	3610.477
13A	15	BIAS	26.0	176.697	13.308	3950.529
13A	15	BIAS	26.0	165.085	12.433	3690.930
13A	15	BIAS	26.0	198.800	14.972	4444.711
13A	15	BIAS	26.0	174.726	13.159	3906.478
13A	15	BIAS	26.0	161.647	12.174	3614.042
13A	15	BIAS	26.0	184.312	13.881	4120.797
13B	15	BIAS	26.0	203.061	15.293	4539.988
13B	15	BIAS	26.0	172.281	12.975	3851.797
15A	15	BIASBE	26.0	166.426	12.534	3720.988
15A	15	BIASBE	26.0	155.704	11.726	3481.174
15A	15	BIASBE	26.0	169.462	12.762	3788.785
15A	15	BIASBE	26.0	170.356	12.830	3808.785

Table A-2 (cont.)

Single Large-Roll Dynamometer Test
Date By Tire Identification Number

Tire ID	Tire Size	Tire Type	Test Press (PSI)	Roll Curvature Corrected: Rolling Force (NT)	Roll Curvature Corrected: Rolling Resistance (lb/k-lb)	Roll Curvature Corrected: Power Absorbed At 50 MPH (watts)
15A	15	BIASBE	26.0	175.046	13.183	3913.625
15A	15	BIASBE	26.0	170.233	12.821	3806.014
180	15	RADIAL	26.0	150.863	11.362	3372.940
180	15	RADIAL	26.0	147.284	11.092	3292.928
200	15	RADIAL	26.0	143.490	10.806	3208.115
200	15	RADIAL	26.0	135.205	10.182	3022.880
210	15	RADIAL	26.0	141.355	10.646	3160.366
210	15	RADIAL	26.0	133.269	10.037	2979.601
210	15	RADIAL	26.0	134.899	10.160	3016.035
220	15	RADIAL	26.0	126.934	9.560	2837.947
220	15	RADIAL	26.0	126.763	9.547	2834.137
230	15	RADIAL	26.0	140.951	10.615	3151.348
230	15	RADIAL	26.0	124.166	9.351	2776.068
240	15	RADIAL	26.0	134.460	10.127	3006.220
240	15	RADIAL	26.0	162.924	12.270	3642.605
250	14	RADIAL	26.0	153.908	11.591	3441.033
250	14	RADIAL	26.0	103.850	7.821	2321.851
260	14	RADIAL	26.0	132.569	9.984	2963.925
260	14	RADIAL	26.0	127.917	9.634	2859.920
270	14	RADIAL	26.0	138.433	10.425	3095.043
270	14	RADIAL	26.0	132.469	9.977	2961.703
290	15	RADIAL	26.0	168.251	12.672	3761.709
300	14	RADIAL	26.0	115.423	8.693	2580.584
300	14	RADIAL	26.0	119.334	8.988	2668.035
320	14	BIASBE	26.0	172.218	12.971	3850.401
320	14	BIASBE	26.0	163.405	12.306	3653.363
340	14	BIASBE	26.0	198.279	14.933	4433.066
340	14	BIASBE	26.0	190.957	14.382	4269.367
350	13	BIAS	26.0	141.134	10.629	3155.434
350	13	BIAS	26.0	179.077	13.487	4003.759
360	13	RADIAL	26.0	136.394	10.273	3049.462
360	13	RADIAL	26.0	126.871	9.555	2836.540
370	13	RADIAL	26.0	156.293	11.771	3494.351
370	13	RADIAL	26.0	119.017	8.964	2660.948
370	13	RADIAL	26.0	125.414	9.446	2803.982
380	13	RADIAL	26.0	159.817	12.036	3573.133
380	13	RADIAL	26.0	129.418	9.747	2893.494
390	13	BIAS	26.0	198.624	14.959	4440.781
390	13	BIAS	26.0	214.622	16.164	4798.461
390	13	BIAS	26.0	160.264	12.070	3583.138
400	15	RADIAL	26.0	152.150	11.459	3401.722
400	15	RADIAL	26.0	142.412	10.726	3184.010
410	13	BIAS	26.0	148.770	11.204	3326.156
410	13	BIAS	26.0	163.047	12.279	3645.350
420	15	RADIAL	26.0	137.440	10.351	3072.844
420	15	RADIAL	26.0	144.335	10.870	3227.007

APPENDIX B

Test Tire Description By Identification Number

B-1

Tire Description
(both studies combined)

ID Number	Manufacturer	Size	Model
010	Goodyear	BR 70X13	Polyglass Radial WT
020	Goodyear	BR 70X13	Polyglass Radial
050	Goodyear	HR 78X14	Polyglass Radial WT
060	Goodyear	H 78X15	Custom Power Cushion Polyglass
070	Goodyear	HR 78X15	Polyglass Radial
080	Goodyear	HR 70X15	Polyglass Radial WT
090	Goodyear	HR 78X15	Custom Polysteel Radial
100	Goodyear	B 78X13	Cushion Belt Polyglass
110	Goodyear	H 78X14	Cushion Belt Polyglass
12A	B.F. Goodrich	HR 78X15	Silvertown Steel Radial
12B	B.F. Goodrich	HR 78X15	Silvertown Steel Radial
13A	B.F. Goodrich	H 78X15	Custom Long Miler
13B	B.F. Goodrich	H 78X15	Custom Long Miler
15A	B.F. Goodrich	HR 78X15	Silvertown Belted
16A	B.F. Goodrich	HR 70X15	Silvertown Lifesaver XL-100
16B	B.F. Goodrich	HR 70X15	Silvertown Lifesaver XL-100
180	Firestone	GR 78X15	Steel Belted Radial
200	Goodyear	HR 78X15	Steel Belted Radial Custom Tread
210	Uniroyal	GR 78X15	Steel Belted Radial PR6
220	Goodyear	GR 78X15	Steel Belted Radial Custom Tread
230	General	GR 78X15	Dual Steel II Radial
240	Uniroyal	LR 78X15	Steel Belted Radial PR6
250	Goodyear	ER 78X14	Steel Belted Radial Custom Tread
260	Uniroyal	FR 78X14	Steel Belted Radial
270	Firestone	FR 78X14	Steel Belted Radial
290	Firestone	HR 78X15	Steel Belted Radial
300	Uniroyal	ER 78X14	Steel Belted Radial
310	Firestone	ER 78X14	Steel Belted Radial
320	Goodyear	E 78X14	Custom Power Belted Cushioned Polyglass
330	Uniroyal	E 78X14	Fastrak Belted
340	Firestone	E 78X14	Sup-R-Belted Deluxe Champion
350	Uniroyal	B 78X13	Fastrak Belted
360	Goodyear	BR 78X13	Steel Belted Radial
370	Firestone	BR 78X13	Steel Belted Radial
380	Uniroyal	BR 78X13	Steel Belted Radial
390	Firestone	B 78X13	Deluxe Champion
400	Uniroyal	HR 78X15	Steel Belted Radial
410	B.F. Goodrich	B 78X13	Silvertown Bias
420	B.F. Goodrich	GR 78X15	Lifesaver 78 Steel Belted Radial