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Tire Rolling Resistance Measurements at Initial Inflation Pressures Of 45 PSIG and 26 PSIG

by

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NOTICE

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I. Introduction

A recent EPA Technical Report [1] presents the results of a program which relates tire rolling resistance measurements conducted on a Clayton twin small-roll dynamometer to those on a LABECO single large-roll (48" diameter) dynamometer. The report extrapolates the results obtained on the LABECO to the road by the application of a curvature correction factor developed as a result of tire testing on both a flat surface machine and a large (67" diameter) roll dynamometer. This factor has been reported in the technical literature [2]. In the EPA study, all tests were conducted at 45 PSIG cold inflation pressure which is the typical tire pressure used for emissions and fuel economy testing on the dynamometer.

In order to determine the effect of tire pressure on rolling resistance, data were collected on the same tires used in the above study at a cold inflation pressure of 26 PSIG. These data were then combined with the 45 PSIG data for statistical comparison.

II. Program Design

A total of 84 tests were conducted on 34 pairs of tires during this study. The basic design of this study was similar to that described in the reference [1] report. The following changes in the test procedure of that report were made for this study:

1) All tests were conducted on a single large-roll dynamometer (the same dynamometer used in the previous study).

2) The Federal Test Procedure (FTP) urban driving schedule was driven prior to a 15-minute 50 MPH-steady-state tire rolling resistance measurement period. The FTP was considered the tire warm-up period.

3) Only two dynamometer horsepower settings were used, 10.5 HP for 14" and 15" tires and 7.4 HP for 13" tires. These dynamometer settings were determined in the same manner as those in reference [1].

4) The initial cold inflation pressure for all tires tested was 26 PSIG.

All other aspects of this study were identical to those described in the reference [1] report. A complete description of each tire tested (tires of both studies) may be found in Appendix A.

III. Analysis

The method used to determine the tire rolling resistance, F_{RR}, and the amount of power absorbed by the tire at 50 mph, P_{ATN}, was to monitor both the power transmitted by the vehicle and the power received by the dynamometer. The difference was considered the power absorbed by the tire. From this absorbed power, the tire rolling resistance was derived. For a complete derivation of the analysis process refer to Appendix B.

The tire rolling resistance and power absorption data generated in this study were then combined with the corresponding data generated during the previous EPA study. The combined data were then corrected for roll curvature using the following equation:

$$\text{Curvature Corrected Rolling Resistance} = F_{RR} \times C_{DR}$$

where

F_{RR} = Tire rolling resistance,

C_{DR} = roll curvature correction factor = $(1 + \frac{r_L}{R})^{-1/2}$,

r_L = tire load radius, and

R = dynamometer roll radius.

The curvature corrected and the rolling resistance and tire power absorption data were then statistically compared. These and the uncorrected data are presented in Appendix C. The percent difference in mean tire rolling resistance values due to inflation pressure was computed according to the following equation:

$$\left[\frac{\text{Mean } F_{RR} \text{ at 26 PSI} - \text{Mean } F_{RR} \text{ at 45 PSI}}{\text{Mean } F_{RR} \text{ at 45 PSI}}\right] \times 100\%$$

An analysis of variance performed on all of the 26 PSI and 45 PSI data indicated that tire pressure has a significant effect on tire rolling resistance. It was found that, in general, the tire rolling resistance decreased 2.21% for each 1 PSI increase. In order to determine if the percent difference was a function of tire type, the analysis was repeated on the data for the radials, bias belted, and bias ply tires of the sample. It was found that in each case, the tire pressure had a significant effect on the rolling resistance with each 1 PSI increase for each tire type.

Table 1

Effects of Inflation Pressure on
Rolling Resistance by Tire Type

Tire Type	Decrease in Rolling Resistance
Radials	2.26%/(PSI increase)
Bias Belted	2.51%/(PSI increase)
Bias	1.10%/(PSI increase)

The effects of increased inflation pressure were investigated further by analyzing the data with respect to both tire size and type. Table 2 presents these results.

Table 2

Effects of Inflation Pressure on
Rolling Resistance by Tire Type and Size

Tire Size and Type	Decrease in Rolling Resistance
13" Radial	1.99%/(PSI increase)
13" Bias Belted	Insufficient Data
13" Bias	0.54%/(PSI increase)
14" Radial	1.77%/(PSI increase)
14" Bias Belted	2.60%/(PSI increase)
14" Bias	Insufficient Data
15" Radial	2.53%/(PSI increase)
15" Bias Belted	3.88%/(PSI increase)
15" Bias	2.15%/(PSI increase)

The above analysis detected a significant effect on rolling resistance due to inflation pressure for all of the above cases except for 13" bias ply tires. It should be noted from Table 2 that 14" and 15" bias belted tires seem to be the most sensitive to tire pressure changes. This may be caused by the reduction in sidewall deflection as the tire pressure is increased.

Scatter plots of the curvature corrected rolling resistance, F_{RR}, and the normalized power absorbed at 50 MPH, P_{ATN}, as a function of tire pressure are presented in Appendix D.

Conclusions/Recommendations

The conclusions of this study are:

1) For the tires tested, tire rolling resistance decreases 2.21% per 1 PSI increase in inflation pressure (assuming a linear effect between 26 and 45 PSIG). It is estimated that a 10% reduction in rolling resistance produces a 2% increase in fuel economy [3]. This translates to approximately a 0.4% increase in fuel economy per 1 PSI inflation pressure increase.

2) The magnitude of the effect of inflation pressure on tire rolling resistance is dependent upon tire size and type. In general, the decrease in rolling resistance per PSI inflation pressure increase is 2.26%, 2.51% and 1.10% for the radial, bias belted and bias ply tires of this sample, respectively.

3) The greatest fuel economy improvement may be obtained by increasing the inflation pressure of bias belted tires.

The data contained in this report indicate that tire inflation pressure plays an important role in a particular tire's rolling resistance and therefore a vehicle's fuel economy. The trend thus far on the part of the automotive industry has been to request lower rolling resistance tires from the tire industry and to increase tire inflation pressures in order to comply with the fuel economy standards. Although an automotive manufacturer can recommend a high inflation pressure, there may have been insufficient incentive to make sure this pressure is maintained by the vehicle owner or new car dealer. Since the Government's concerns are with fuel consumption, perhaps a public awareness campaign should be launched stressing the effects of tire rolling resistance and the importance of proper tire pressure with respect to fuel economy. This campaign could be sponsored by the automotive manufacturers, an automotive association (MVMA, SAE, etc.), or by the government (EPA, DOT, DOE, etc.). The effectiveness of the campaign could be evaluated through the EPA Emission Factor Program.

In conjunction with the public awareness campaign, EPA should conduct a survey of new car dealerships to determine if dealers are routinely setting new car tire pressures to the manufacturer's specifications. If not, lower, more representative tire pressures should be required when determining dynamometer road load settings.

Perhaps all tires on new light-duty vehicles should come equipped with tire pressure regulating/warning systems to alert the vehicle owner to under or over inflated tire pressures. This would aid the vehicle owner in the maintenance of the recommended tire pressure.

References

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7. Schuring, D.J., "The Energy Loss of Tires on Twin Rolls, Drum, and Flat Roadway - A Uniform Approach," Society of Automotive Engineers, SAE 770875.

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9. Curtis, W.W., "Low Power Loss Tires," Society of Automotive Engineers, SAE 690108.

10. Clark, S.K., "Rolling Resistance Forces in Pneumatic Tires," University of Michigan Report DOT-TSC-76-1; Prepared for The Department of Transportation, Transportation Systems Center, Cambridge, Mass., January 1976.

11. Thompson, G.D., "Light-Duty Vehicle Road Load Determination," EPA Technical Support Report for Regulatory Action, LDTP-76-03, December 1976.

APPENDIX A

Two Study Tire Description

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

APPENDIX B

Methodology for Determining Tire Rolling Resistance

Methodology Utilized to Determine Tire Rolling Resistance

The power absorbed by the tire was computed each second of data collected according to the following equations:

$$P_{AT} = P_{engine} - P_{abs.\ diff.} - P_{bearing\ losses\ dyno} \quad 1$$

$$= T_{eng}W_E - T_{diff}W_E - T_{LC}W_D - T_{BL}W_D \quad 2$$

$$= (T_{eng} - T_{diff})W_E - (T_{LC} + T_{BL})W_D \quad 3$$

where

P_{AT} = the power absorbed by the tire at the test speed

T_{eng} = torque from the engine/transmission (measured by the driveshaft torque sensor)

T_{diff} = torque required to revolve the rear axle and associated bearings and gearing which make up the differential. Note: This quantity includes any effects due to brake drag.

T_{LC} = total torque measured by the dynamometer load cell

T_{BL} = torque due to bearing and frictional losses in the dynamometer

W_E and W_D = the angular velocities of the vehicle driveshaft and dynamometer roll, respectively.

From each P_{AT} the rolling force was then derived as follows:

$$P_{AT} = T_T W_T \quad 4$$

where T_T is the torque at the tire/roll interface and W_T is the angular velocity of the tire. However, T_T can be defined as the product of a force and a lever arm as follows:

$$T_T = F_R \times r \quad 5$$

where F_R is the rolling force of the tire and r is the tire radius. Substituting equation 5 into 4 yields:

$$P_{AT} = (F_R \times r)\ W_T \quad 6$$

Since the angular velocity W_T can be represented as a ratio of the linear velocity, V_T, and the radius of the tire, r, a substitution for W_T in equation 6 produces:

$$P_{AT} = \frac{(F_R \times r)V_T}{r} = F_R V_T \qquad 7$$

the linear velocity V_T is in actuality the ground o test surface velocity. However, with all vehicle tests on dynamometers, a certain amount of slip between the tire and the dynamometer roll occurs. Therefore, the vehicle linear velocity, the one parameter common to both dynamometers, rather than the dynamometer-roll linear velocity was utilized for this analysis. Therefore, F_R can be expressed as;

$$F_R = \frac{P_{AT}}{V_T} \qquad 8$$

where V_T is the vehicle speed.

Of all the parameters affecting tire power absorption, the vertical load on the tire has yet to be discussed. In general, tire power absorption is directly proportional to the load upon it.[2] As the vertical load increases, the tire power absorption also increases. Therefore, all the above computations are a function of the vertical load under which a particular set of tires was tested. The vertical load used for this experiment was arrived at by weighing the rear portion of each test vehicle with a full tank of fuel and a driver. Fuel was added to each test vehicle at the completion of every second test in order to maintain as constant a vertical load as possible. However, the vertical load of the two test vehicles differed, therefore, making direct tire rolling force, F_R, data comparsions difficult. By calculating the ratio of F_R to the test vertical load, F_{ZT}, all tire test results cold then be directly compared. This is expressed in the equation below:

$$F_{RR} = \frac{F_R}{F_{ZT}} \qquad 9$$

However, statements concerning the power absorbed at 50 mph, P_{AT}, for all the data still could not be made. Since the tire rolling force, F_R, is nearly linear with vertical load, [2] [3] [4] estimates of the power absorbed at 50 mph can be obtained using a form of equation 9. Using the rolling resistance values, F_{RR}, previously obtained, a standard vertical load was chosen and the power absorbed at 50 mph was predicted. The equations presented below outline this process:

$$F_{RN} = F_R \times F_{ZN} \qquad 10$$

$$P_{ATN} = F_{RN} \times 50 \text{ mph} \qquad 11$$

where F_{RR} is as defined in equation 9 and

F_{RN} = normalized F_R

F_{ZN} = 2.985×10^3 lbs.

P_{ATN} = normalized P_{AT}

The standard vertical load was chosen to be the rear weight of the Ford stationwagon used to test 14" and 15" tires.

APPENDIX C

Normalized Test Results by Tire Identification Number

Table C-1

Normalized Test Results by Tire Identification Number

TIRE ID	ROLLING RESISTANCE (LB/K-LB)	ROLLING FORCE (NT)	ABSORBED AT 50 MPH (WATTS)	ROLL CURVATURE CORRECTED ROLLING RESISTANCE (LB/K-LB)	ROLL CURVATURE CORRECTED ROLLING FORCE (NT)	ROLL CURVATURE CORRECTED ABSORBED AT 50 MPH (WATTS)	TIRE SIZE	TYPE CODE	TEST PRESS. (PSI)
010	15.481	205.552	4595.684	12.710	168.758	3773.056	13	3.	26.0
010	11.671	154.963	3464.614	9.582	127.225	2844.448	13	3.	26.0
020	13.604	180.634	4038.560	11.169	148.301	3315.658	13	3.	26.0
050	13.097	173.895	3887.898	10.517	139.638	3121.982	14	3.	26.0
050	14.587	193.691	4330.496	11.713	155.534	3477.388	14	3.	26.0
050	13.831	183.651	4106.027	11.106	147.472	3297.140	14	3.	26.0
060	13.093	173.850	3886.888	10.435	138.558	3097.850	15	4.	26.0
060	15.019	199.416	4458.477	11.970	158.935	3553.406	15	4.	26.0
070	15.705	208.532	4662.309	12.580	167.034	3734.509	15	3.	26.0
070	12.034	159.782	3572.351	9.639	127.985	2861.453	15	3.	26.0
080	17.295	229.646	5134.352	13.819	183.487	4102.344	15	3.	26.0
080	15.140	201.025	4494.453	12.097	160.619	3591.068	15	3.	26.0
090	11.021	146.343	3271.891	8.828	117.221	2620.785	15	3.	26.0
090	10.940	145.264	3247.776	8.763	116.356	2601.468	15	3.	26.0
090	10.687	141.905	3172.682	8.560	113.666	2541.318	15	3.	26.0
090	11.449	152.022	3398.861	9.171	121.770	2722.488	15	3.	26.0
090	10.989	145.918	3262.385	8.802	116.880	2613.170	15	3.	26.0
090	11.600	154.020	3443.531	9.292	123.370	2758.268	15	3.	26.0
090	11.242	149.268	3337.283	9.005	119.564	2673.164	15	3.	26.0
100	15.439	204.999	4583.313	12.583	167.074	3735.400	13	4.	26.0
100	15.373	204.116	4563.563	12.529	166.355	3719.303	13	4.	26.0
100	14.709	195.311	4366.715	11.988	159.178	3558.873	13	4.	26.0
110	15.783	209.560	4685.273	12.642	167.858	3752.904	14	4.	26.0
110	15.786	209.610	4686.395	12.645	167.898	3753.802	14	4.	26.0
12A	14.514	192.716	4308.684	11.626	154.366	3451.255	15	3.	26.0
12A	12.190	161.858	3618.787	9.764	129.648	2898.648	15	3.	26.0
12B	13.930	184.958	4135.246	11.172	148.336	3316.467	15	3.	26.0
12B	14.345	190.476	4258.602	11.505	152.762	3415.398	15	3.	26.0
13A	15.298	203.128	4541.480	12.162	161.487	3610.477	15	5.	26.0
13A	16.552	219.781	4913.809	13.159	174.726	3906.478	15	5.	26.0
13A	15.639	207.654	4642.680	12.433	165.085	3690.930	15	5.	26.0
13A	17.460	231.839	5183.395	13.881	184.312	4120.797	15	5.	26.0
13A	16.739	222.260	4969.219	13.308	176.697	3950.529	15	5.	26.0
13A	15.313	203.329	4545.965	12.174	161.647	3614.042	15	5.	26.0
13A	18.833	250.063	5590.832	14.972	198.800	4444.711	15	5.	26.0
13B	16.300	216.433	4838.941	12.975	172.281	3851.797	15	5.	26.0
13B	19.212	255.102	5703.504	15.293	203.061	4539.988	15	5.	26.0
15A	16.098	213.747	4778.902	12.830	170.356	3808.785	15	4.	26.0
15A	14.713	195.362	4367.848	11.726	155.704	3481.174	15	4.	26.0
15A	16.086	213.592	4775.426	12.821	170.233	3806.014	15	4.	26.0
15A	15.726	208.815	4668.617	12.534	166.426	3720.888	15	4.	26.0
15A	16.541	219.631	4910.445	13.183	175.046	3913.625	15	4.	26.0
15A	16.013	212.625	4753.809	12.762	169.462	3788.785	15	4.	26.0
180	13.796	183.189	4095.682	11.092	147.284	3292.928	15	3.	26.0
180	14.132	187.640	4195.199	11.362	150.863	3372.940	15	3.	26.0
200	12.712	168.795	3773.883	10.182	135.205	3022.880	15	3.	26.0
200	13.491	179.139	4005.138	10.806	143.490	3208.115	15	3.	26.0
210	12.468	165.552	3701.368	10.037	133.269	2979.601	15	3.	26.0
210	13.225	175.596	3925.921	10.646	141.355	3160.366	15	3.	26.0
210	12.621	167.576	3746.627	10.160	134.899	3016.035	15	3.	26.0
220	11.890	157.878	3529.785	9.560	126.934	2837.947	15	3.	26.0
220	11.874	157.666	3525.046	9.547	126.763	2834.137	15	3.	26.0
230	13.269	176.189	3939.185	10.615	140.951	3151.348	15	3.	26.0
230	11.689	155.207	3470.085	9.351	124.166	2776.068	15	3.	26.0
240	12.722	168.920	3776.659	10.127	134.460	3006.220	15	3.	26.0

Table C-1 continued

TIRE ID	ROLLING RESISTANCE (LB/K-LB)	ROLLING FORCE (NT)	ABSORBED AT 50 MPH (WATTS)	ROLL CURVATURE CORRECTED ROLLING RESISTANCE (LB/K-LB)	ROLL CURVATURE CORRECTED ROLLING FORCE (NT)	ROLL CURVATURE CORRECTED ABSORBED AT 50 MPH (WATTS)	TIRE SIZE	TYPE CODE	TEST PRESS. (PSI)
240	15.415	204.678	4576.137	12.270	162.924	3642.605	15	3.	26.0
250	14.101	187.236	4186.172	11.591	153.908	3441.033	14	3.	26.0
250	9.515	126.338	2824.636	7.821	103.850	2321.851	14	3.	26.0
260	12.326	163.665	3659.167	9.984	132.569	2963.925	14	3.	26.0
260	11.894	157.922	3530.766	9.634	127.917	2859.920	14	3.	26.0
270	12.714	168.821	3774.443	10.425	138.433	3095.043	14	3.	26.0
270	12.167	161.547	3611.833	9.977	132.469	2961.703	14	3.	26.0
290	15.820	210.051	4696.266	12.672	168.251	3761.709	15	3.	26.0
300	10.934	145.175	3245.785	8.988	119.334	2668.035	14	3.	26.0
300	10.575	140.417	3139.397	8.693	115.423	2580.584	14	3.	26.0
320	15.193	201.735	4510.324	12.306	163.405	3653.363	14	4.	26.0
320	16.013	212.615	4753.582	12.971	172.218	3850.401	14	4.	26.0
340	17.755	235.750	5270.828	14.382	190.957	4269.367	14	4.	26.0
340	18.436	244.789	5472.922	14.933	198.279	4433.066	14	4.	26.0
350	16.508	219.189	4900.563	13.487	179.077	4003.759	13	5.	26.0
350	13.010	172.747	3862.220	10.629	141.134	3155.434	13	5.	26.0
360	11.624	154.344	3450.779	9.555	126.871	2836.540	13	3.	26.0
360	12.497	165.930	3709.808	10.273	136.394	3049.462	13	3.	26.0
370	10.905	144.789	3237.163	8.964	119.017	2660.948	13	3.	26.0
370	14.320	190.137	4251.035	11.771	156.293	3494.351	13	3.	26.0
370	11.491	152.572	3411.170	9.446	125.414	2803.982	13	3.	26.0
380	14.660	194.661	4352.172	12.036	159.817	3573.133	13	3.	26.0
380	11.872	157.635	3524.353	9.747	129.418	2893.494	13	3.	26.0
390	19.736	262.054	5858.930	16.164	214.622	4798.461	13	5.	26.0
390	14.737	195.683	4375.016	12.070	160.264	3583.138	13	5.	26.0
390	18.265	242.520	5422.203	14.959	198.624	4440.781	13	5.	26.0
400	13.407	178.015	3980.013	10.726	142.412	3184.010	15	3.	26.0
400	14.324	190.187	4252.152	11.459	152.150	3401.722	15	3.	26.0
410	14.993	199.080	4450.977	12.279	163.047	3645.350	13	5.	26.0
410	13.680	181.648	4061.240	11.204	148.770	3326.156	13	5.	26.0
420	13.520	179.521	4013.690	10.870	144.335	3227.007	15	3.	26.0
420	12.874	170.945	3821.945	10.351	137.440	3072.844	15	3.	26.0
020	6.008	79.770	1782.857	4.927	65.411	1461.943	13	3.	45.0
020	12.160	161.452	3608.446	9.971	132.391	2958.926	13	3.	45.0
020	14.681	194.933	4358.250	12.053	160.040	3578.123	13	3.	26.0
060	9.783	129.896	2903.176	7.797	103.527	2313.831	15	4.	45.0
060	7.962	105.717	2362.775	6.346	84.256	1883.131	15	4.	45.0
070	5.405	71.770	1604.059	4.324	57.416	1283.247	15	3.	45.0
080	8.145	108.150	2417.152	6.516	86.520	1933.722	15	3.	45.0
080	11.409	151.477	3385.511	9.127	121.182	2708.409	15	3.	45.0
12B	10.997	146.005	3263.212	8.798	116.804	2610.569	15	3.	45.0
12B	9.919	131.699	2943.473	7.935	105.359	2354.778	15	3.	45.0
12B	9.836	130.598	2918.865	7.869	104.478	2335.092	15	3.	45.0
13A	8.329	110.581	2471.485	6.638	88.133	1969.773	15	5.	45.0
13A	15.967	212.003	4738.266	12.726	168.966	3776.397	15	5.	45.0
13B	11.463	152.202	3401.715	9.113	121.001	2704.364	15	5.	45.0
16A	11.475	152.359	3405.224	9.088	120.668	2696.937	15	3.	45.0
16B	11.427	151.719	3390.920	9.039	120.010	2682.218	15	3.	45.0
16B	11.875	157.663	3523.768	9.393	124.711	2787.301	15	3.	45.0
180	11.628	154.385	3450.505	9.349	124.126	2774.206	15	3.	45.0
200	4.907	65.146	1456.013	3.931	52.182	1166.266	15	3.	45.0
200	7.279	96.650	2160.127	5.830	77.417	1730.261	15	3.	45.0
210	6.335	84.118	1880.037	5.093	67.631	1511.550	15	3.	45.0
220	8.235	109.334	2443.615	6.621	87.905	1964.666	15	3.	45.0
220	5.582	74.114	1656.448	4.488	59.588	1331.784	15	3.	45.0
230	10.136	134.572	3007.684	8.139	108.061	2415.170	15	3.	45.0
230	6.404	85.028	1900.376	5.142	68.277	1526.002	15	3.	45.0
240	10.468	138.981	3106.225	8.333	110.629	2472.555	15	3.	45.0
240	7.149	94.924	2121.551	5.691	75.559	1688.754	15	3.	45.0
250	8.327	110.563	2471.083	6.778	89.998	2011.461	14	3.	45.0

Table C-1 (concluded)

TIRE ID	ROLLING RESISTANCE (LB/K-LB)	ROLLING FORCE (NT)	ABSORBED AT 50 MPH (WATTS)	ROLL CURVATURE CORRECTED ROLLING RESISTANCE (LB/K-LB)	ROLL CURVATURE CORRECTED ROLLING FORCE (NT)	ROLL CURVATURE CORRECTED ABSORBED AT 50 MPH (WATTS)	TIRE SIZE	TYPE CODE	TEST PRESS. (PSI)
250	11.978	159.039	3554.522	9.750	129.458	2893.381	14	3.	45.0
250	7.852	104.248	2329.943	6.392	84.858	1896.573	14	3.	45.0
250	8.054	106.932	2389.930	6.556	87.043	1945.403	14	3.	45.0
260	9.317	123.708	2764.874	7.537	100.080	2236.783	14	3.	45.0
260	7.737	102.725	2295.904	6.259	83.105	1857.386	14	3.	45.0
270	8.598	114.163	2551.543	6.973	92.586	2069.301	14	3.	45.0
270	8.977	119.187	2663.830	7.280	96.661	2160.366	14	3.	45.0
290	10.650	141.404	3160.379	8.531	113.265	2531.463	15	3.	45.0
300	9.846	130.734	2921.905	7.995	106.156	2372.587	14	3.	45.0
300	12.584	167.087	3734.394	10.218	135.675	3032.328	14	3.	45.0
300	8.671	115.121	2572.954	7.041	93.478	2089.239	14	3.	45.0
310	12.081	160.403	3585.007	9.822	130.408	2914.611	14	3.	45.0
310	7.582	100.672	2250.019	6.164	81.846	1829.265	14	3.	45.0
310	6.074	80.645	1802.416	4.938	65.564	1465.364	14	3.	45.0
310	11.143	147.946	3306.593	9.059	120.280	2688.260	14	3.	45.0
320	9.453	125.506	2805.059	7.657	101.660	2272.098	14	4.	45.0
320	9.049	120.146	2685.263	7.330	97.318	2175.063	14	4.	45.0
320	9.143	121.398	2713.245	7.406	98.332	2197.729	14	4.	45.0
330	14.467	192.077	4292.922	11.733	155.774	3481.560	14	4.	45.0
330	11.732	155.767	3481.392	9.515	126.327	2823.409	14	4.	45.0
330	10.645	141.334	3158.815	8.633	114.622	2561.799	14	4.	45.0
340	12.026	159.679	3568.826	9.729	129.180	2887.180	14	4.	45.0
340	11.630	154.410	3451.063	9.409	124.918	2791.910	14	4.	45.0
340	10.880	144.461	3228.703	8.802	116.869	2612.021	14	4.	45.0
350	15.710	208.586	4661.898	12.851	170.623	3813.433	13	5.	45.0
350	11.524	153.007	3419.715	9.427	125.160	2797.327	13	5.	45.0
370	8.892	118.062	2638.676	7.300	96.929	2166.353	13	3.	45.0
370	10.681	141.815	3169.557	8.769	116.430	2602.206	13	3.	45.0
400	10.808	143.499	3207.203	8.646	114.799	2565.762	15	3.	45.0
410	18.624	247.276	5526.621	15.253	202.519	4526.301	13	5.	45.0
410	12.388	164.479	3676.104	10.146	134.708	3010.729	13	5.	45.0
410	13.689	181.753	4062.173	11.211	148.856	3326.920	13	5.	45.0
420	7.410	98.388	2198.972	5.950	79.006	1765.774	15	3.	45.0
420	6.654	88.346	1974.533	5.343	70.942	1585.550	15	3.	45.0

Tire Type Code

3 = Radial
4 = Bias Belted
5 = Bias

APPENDIX D

Plots of P_{ATN} and F_{RR} as a Function of Inflation Pressure

<SCATTER VAR=6;9 CASFS=ALL INTERVAL=(1000,6000);(7,64)>

SCATTER PLOT

N= 149 OUT OF 149 6.PATNC VS. 9.PSI

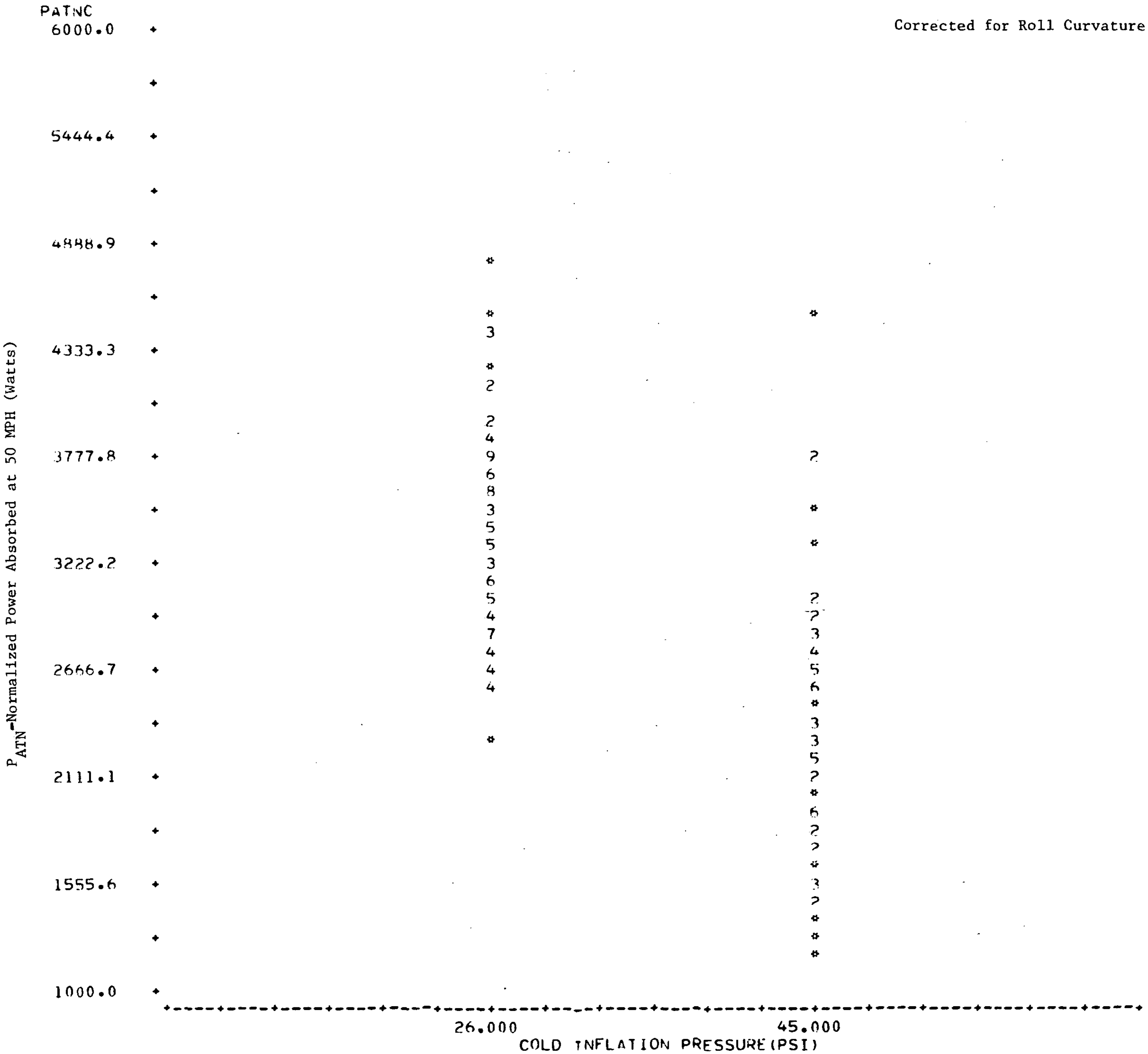


Figure D-1

Power Absorbed at 50 MPH as a Function of Inflation Pressure

<SCATTER VAR=6;9 CASES=V8:3 INTERVAL=(1000.6000);(7.64)>

SCATTER PLOT CASES=TYPE:3
N= 97 OUT OF 97 6.PATNC VS. 9.PSI

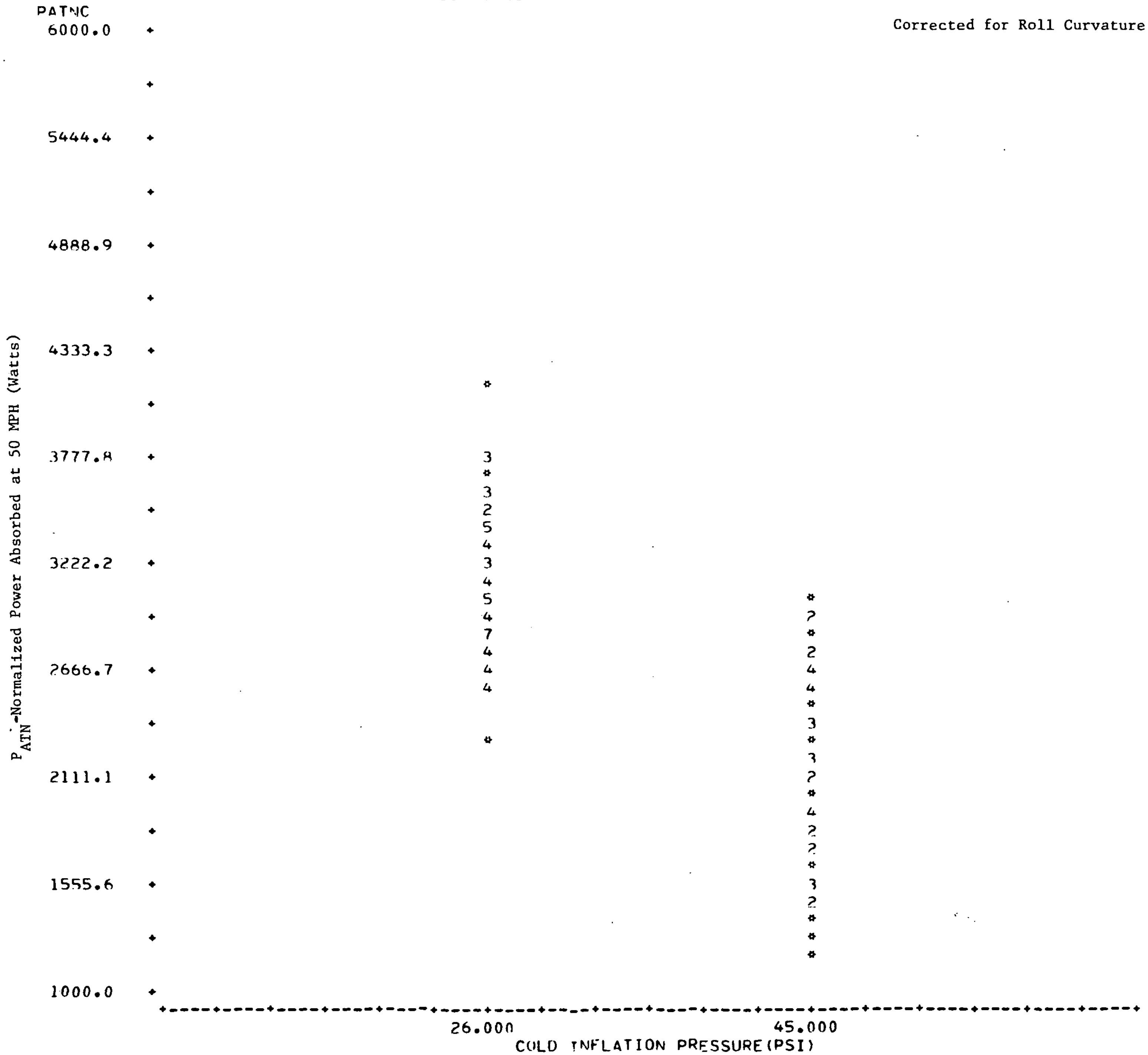


Figure D-2

Power Absorbed at 50 MPH as a Function of Inflation Pressure for Radial Ply Tires

<SCATTER VAR=6;9 CASES=V8:4 INTERVAL=(1000,6000);(7.64)>

SCATTER PLOT CASES=TYPE:BIASBE
N= 28 OUT OF 28 6.PATNC VS. 9.PSI

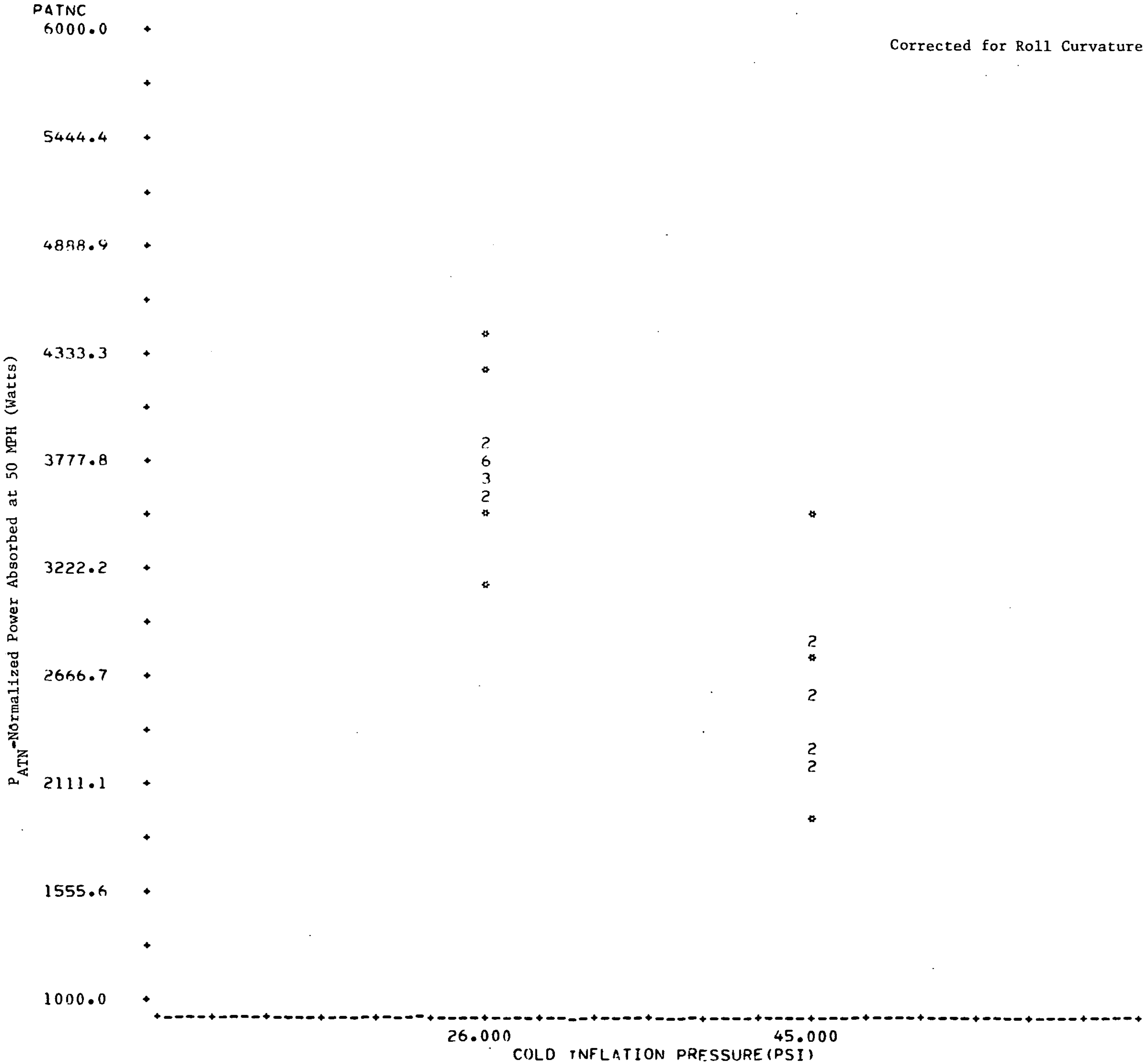


Figure D-3

Power Absorbed at 50 MPH as a Function of Inflation Pressure for Bias Belted Tires

<SCATTER VAR=6:9 CASES=V8:5 INTERVAL=(1000,6000):(7,64)>

SCATTER PLOT CASES=TYPE:BIAS
N= 24 OUT OF 24 6.PATNC VS. 9.PSI

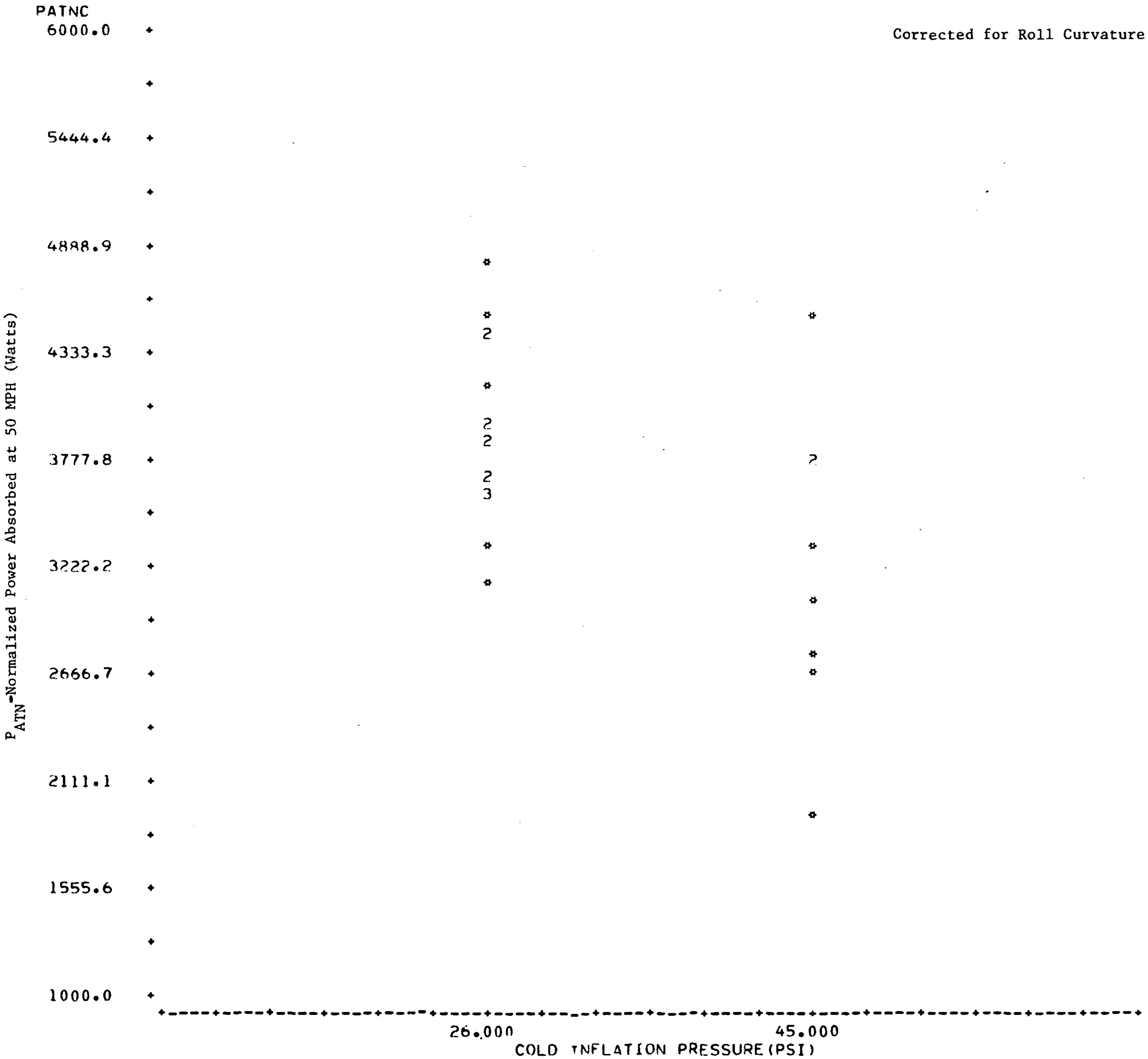


Figure D-4

Power Absorbed at 50 MPH as a Function of Inflation Pressure for Bias Ply Tires

<SCATTER BYSTRATA VAR=6;9 CASES=V9:3 STRAT=V7 INTERVAL=(1000,6000):(7,64)>

SCATTER PLOT <13> SI E:13 CASES=TYPE:3
N= 15 OUT OF 15 6.PATNC VS. 9.PSI

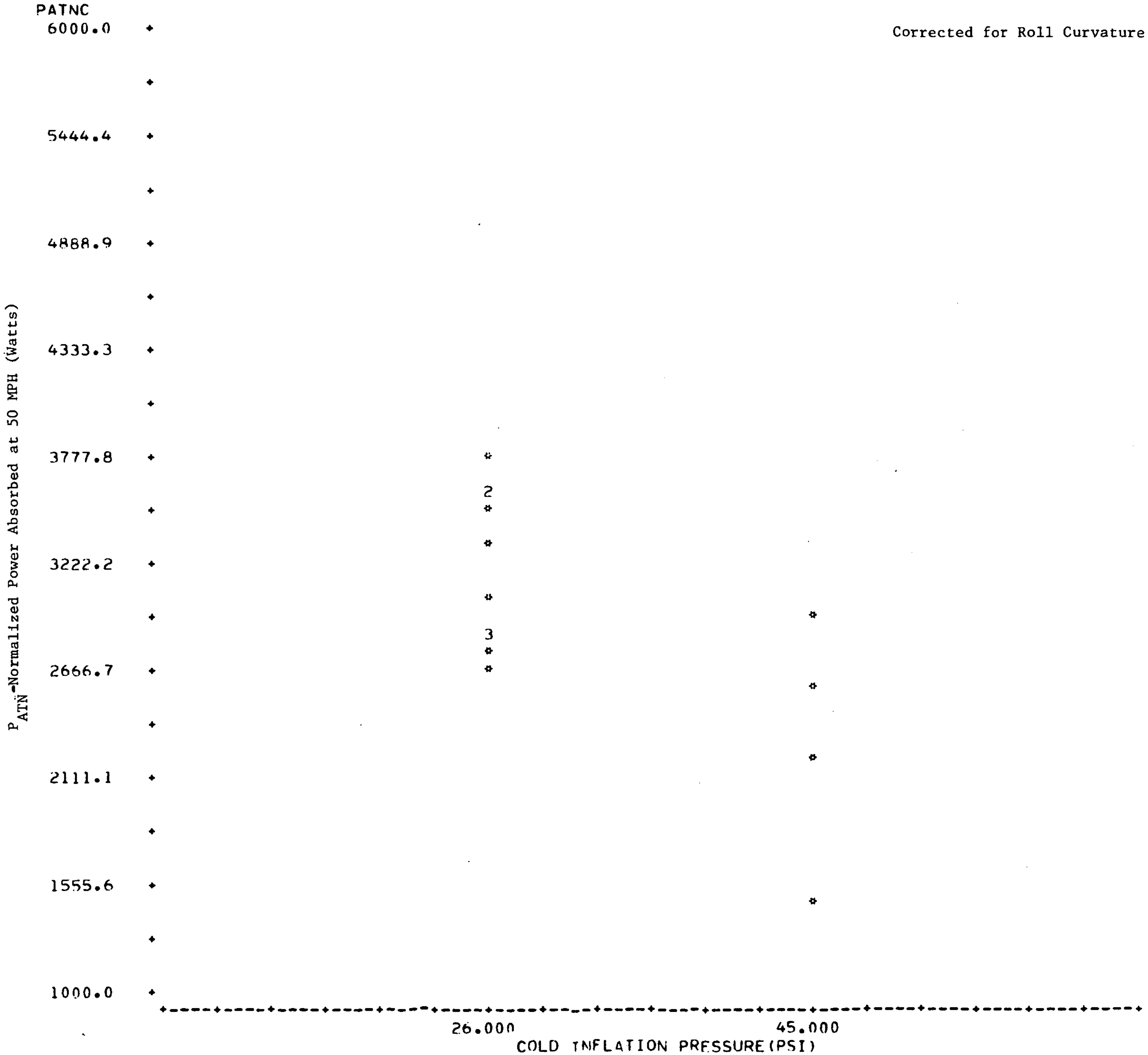


Figure D-5

Power Absorbed at 50 MPH as a Function of Inflation Pressure for 13" Radial Tires

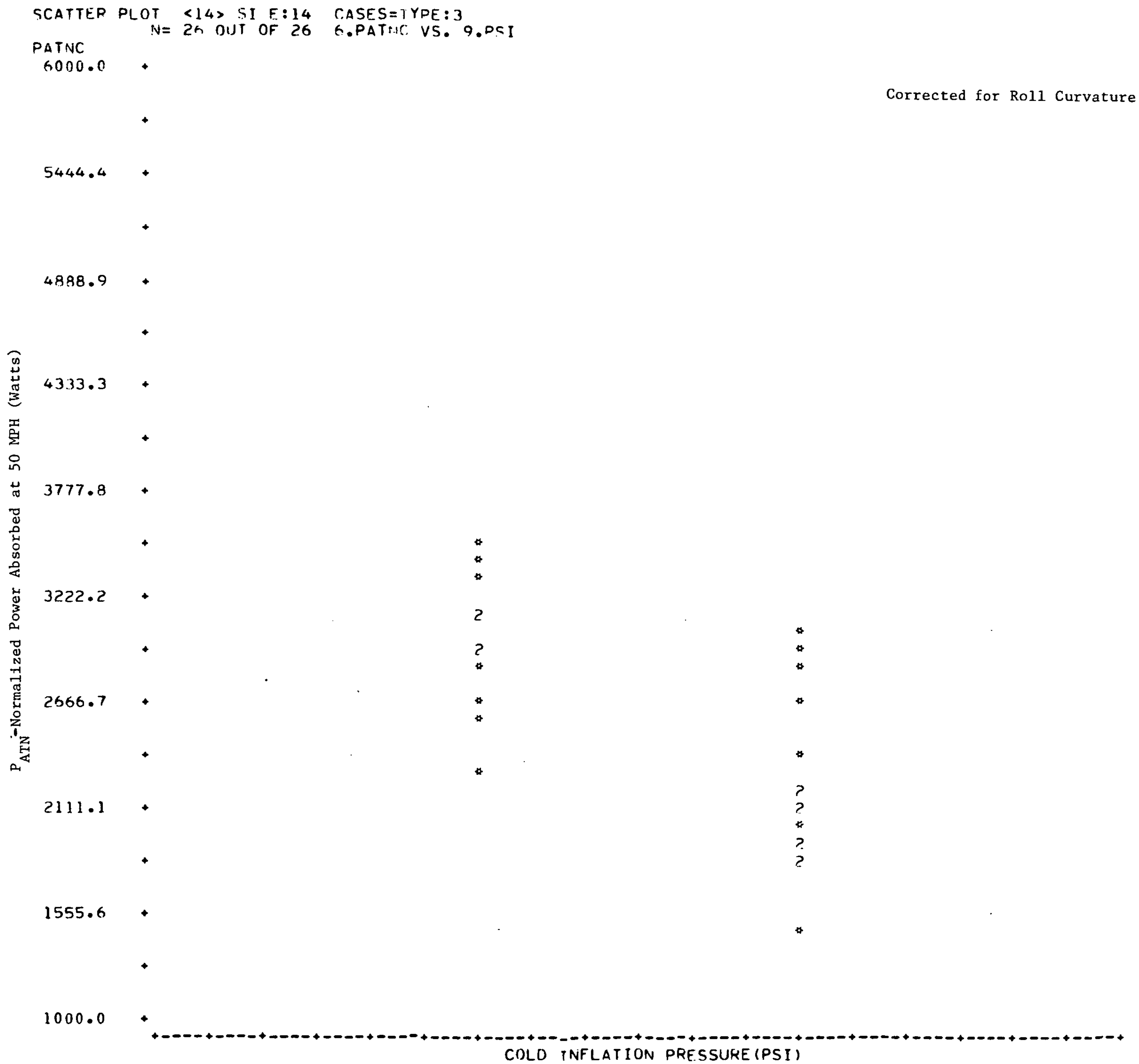


Figure D-6

Power Absorbed at 50 MPH as a Function of Inflation Pressure for 14" Radial Tires

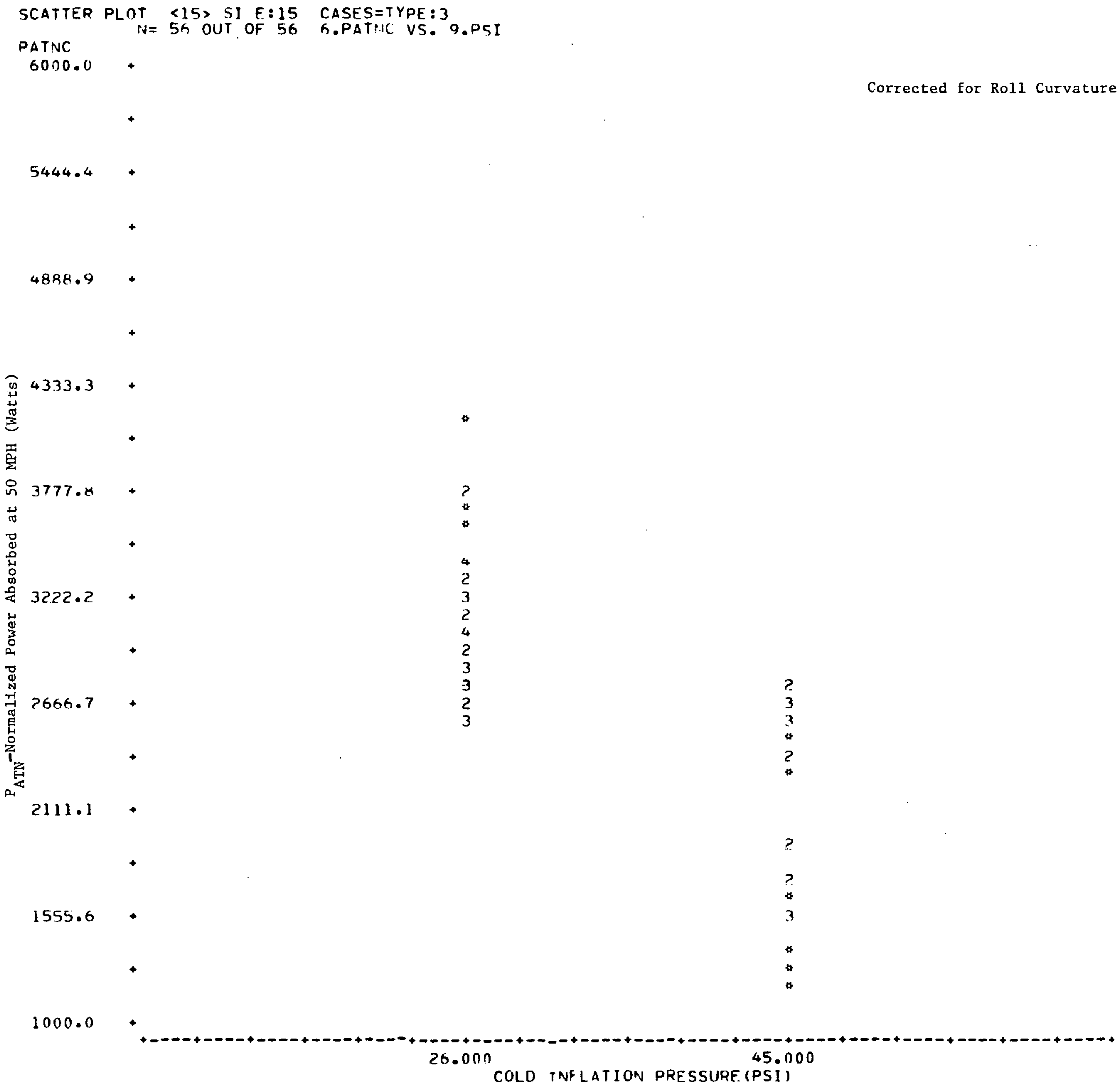


Figure D-7

Power Absorbed at 50 MPH as a Function of Inflation Pressure for 15" Radial Tires

<SCATTER BYSTRATA VAR=6;9 CASES=V8:4 STRAT=V7 INTERVAL=(1000,6000);(7,64)>

SCATTER PLOT <13> SI E:13 CASES=TYPE:BIASBE
N= 3 OUT OF 3 6.PATNC VS. 9.PSI

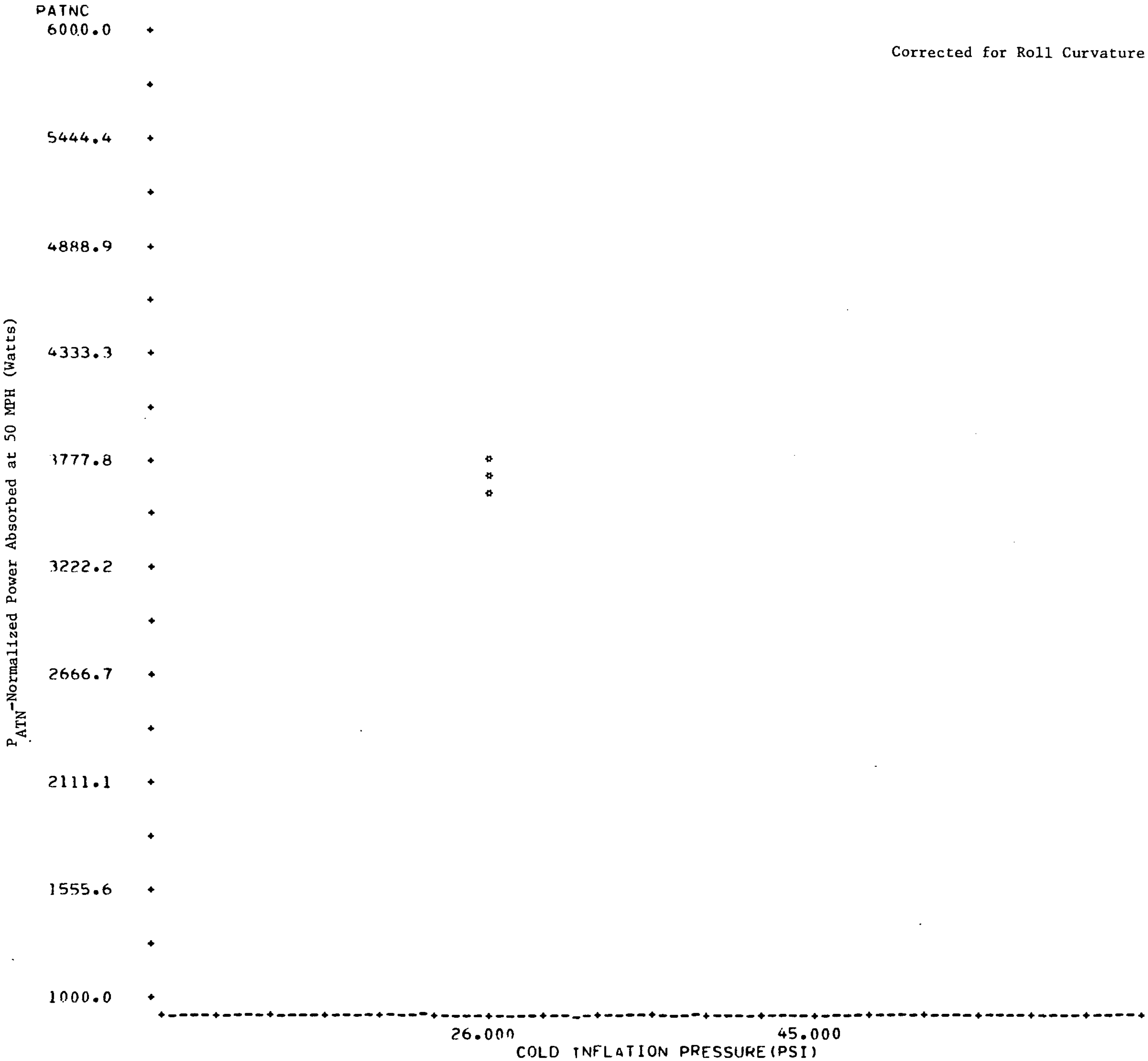


Figure D-8

Power Absorbed at 50 MPH as a Function of Inflation Pressure for 13" Bias Belted Tires

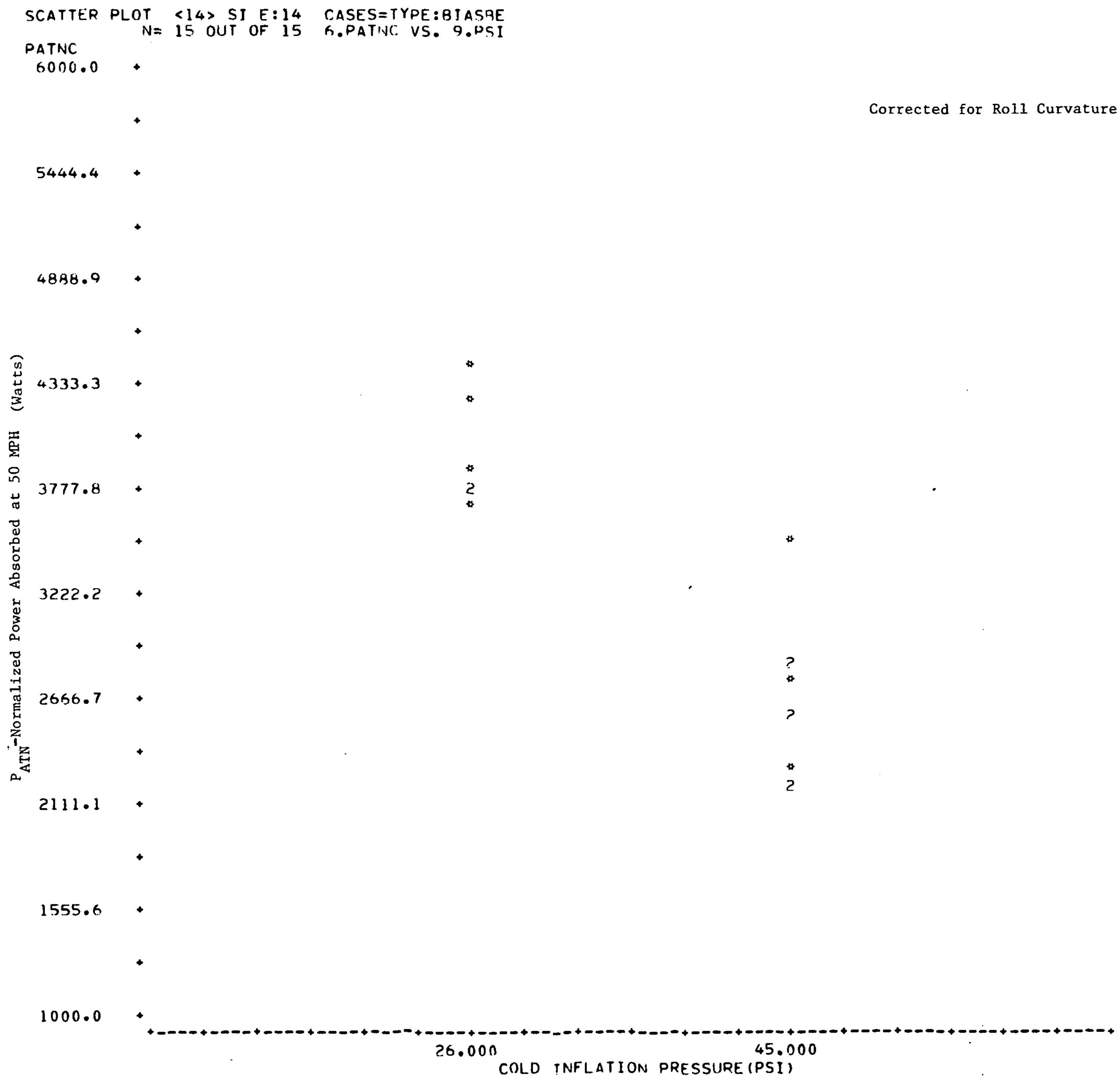


Figure D-9

Power Absorbed at 50 MPH as a Function of Inflation Pressure for 14" Bias Belted Tires

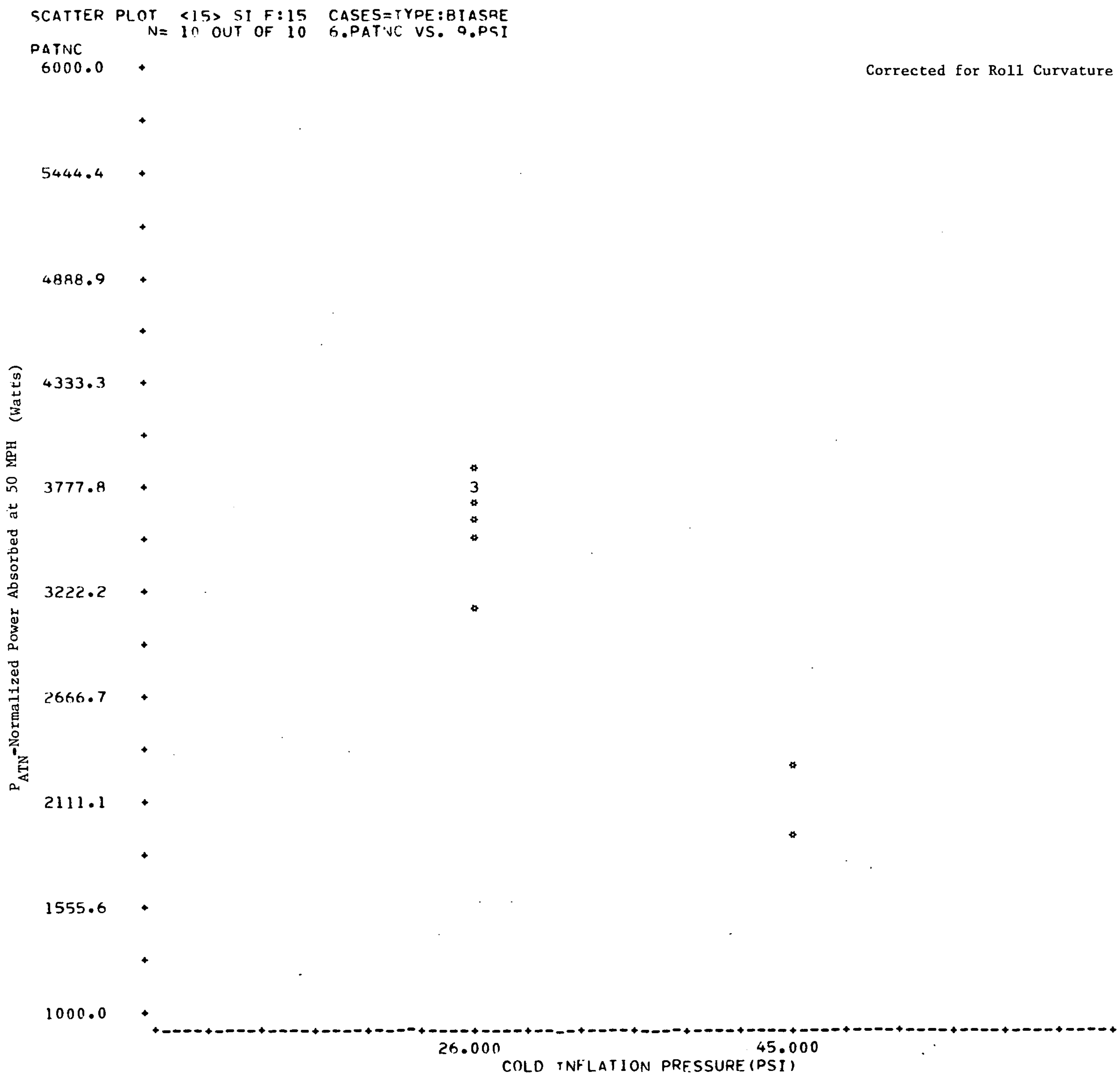


Figure D-10

Power Absorbed at 50 MPH as a Function of Inflation Pressure
for 15" Bias Belted Tires

<SCATTER BYSTRATA VAR=6;9 CASES=V8:5 STRAT=V7 INTERVAL=(1000,6000):(7,64)>

SCATTER PLOT <13> SI E:13 CASES=TYPE:BIAS
N= 12 OUT OF 12 6.PATNC VS. 9.PSI

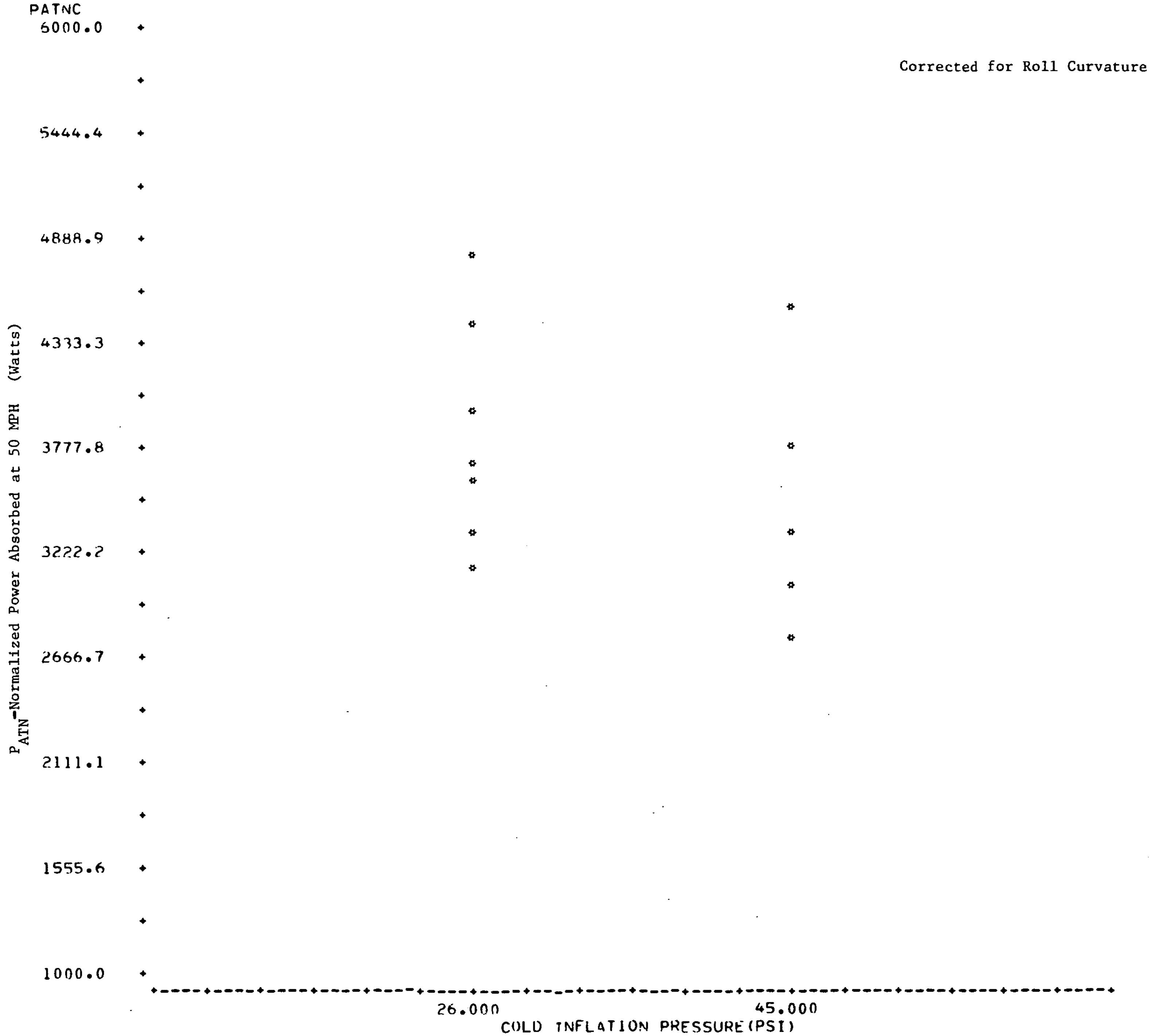


Figure D-11

Power Absorbed at 50 MPH as a Function of Inflation Pressure for 13" Bias Ply Tires

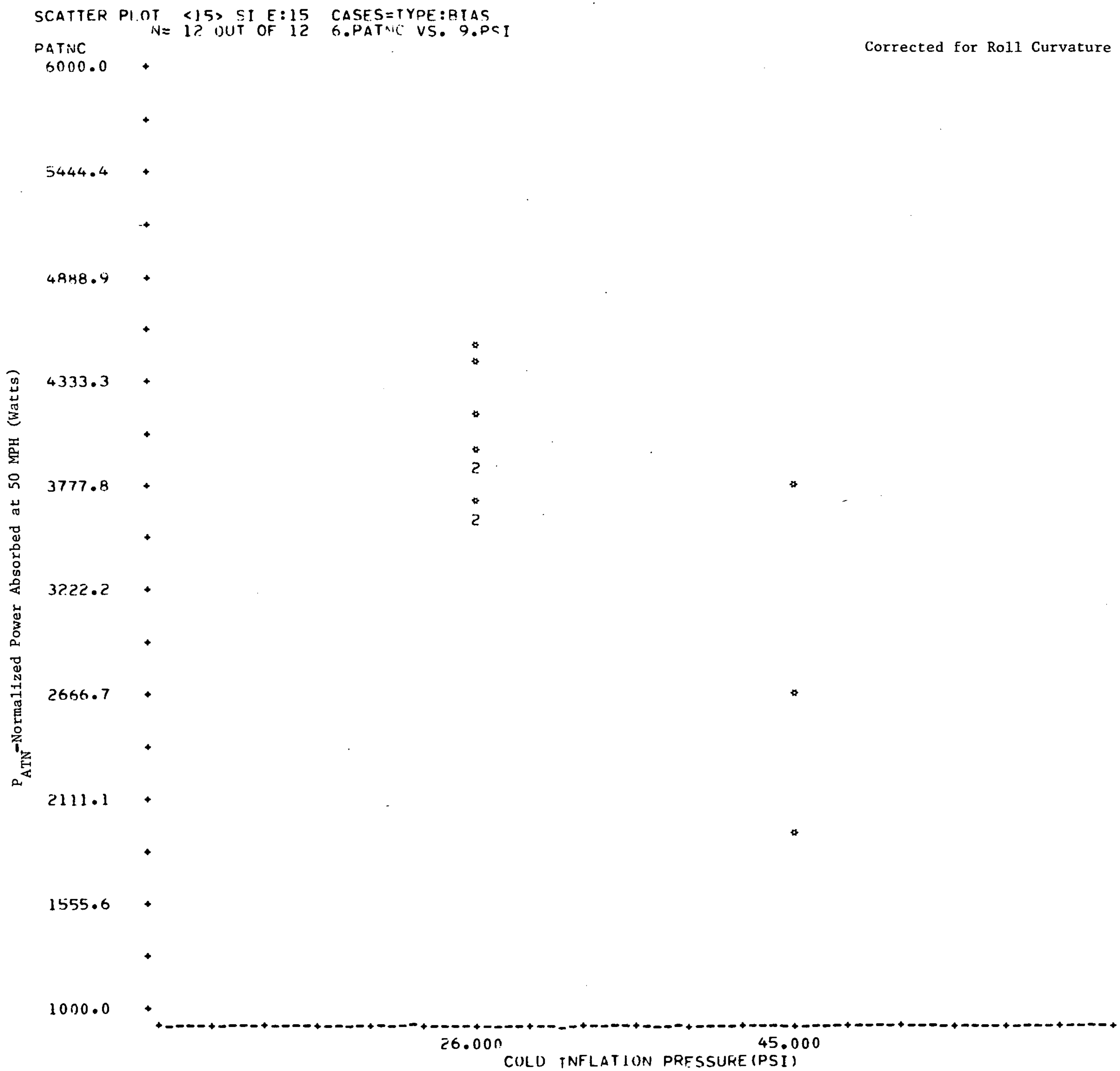


Figure D-12

Power Absorbed at 50 MPH as a Function of Inflation Pressure for 15" Bias Ply Tires

<SCATTER VAR=4:9 CASES=ALL STRAT=NONE INTERVAL=(3.0,21.6):(7,64)>

SCATTER PLOT

N= 149 OUT OF 149 4.FRRC VS. 9.PSI

Corrected for Roll Curvature

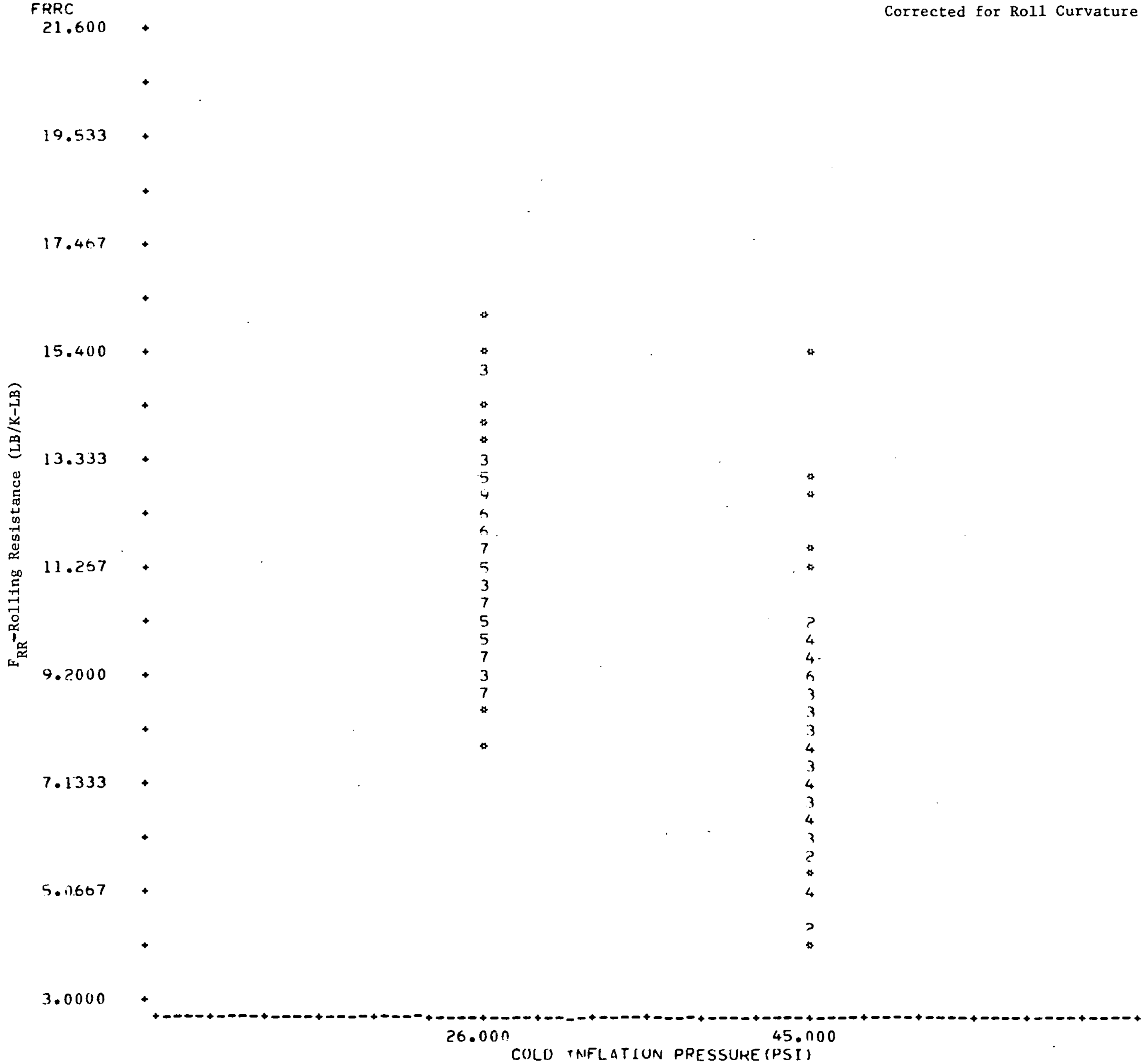


Figure D-13

Tire Rolling Resistance as a Function of Inflation Pressure

<SCATTER VAR=4;9 CASES=V8:3 INTERVAL=(3.0,21.6);(7,64)>

SCATTER PLOT CASES=TYPE:3
N= 97 OUT OF 97 4.FRRC VS. 9.PSI

Corrected for Roll Curvature

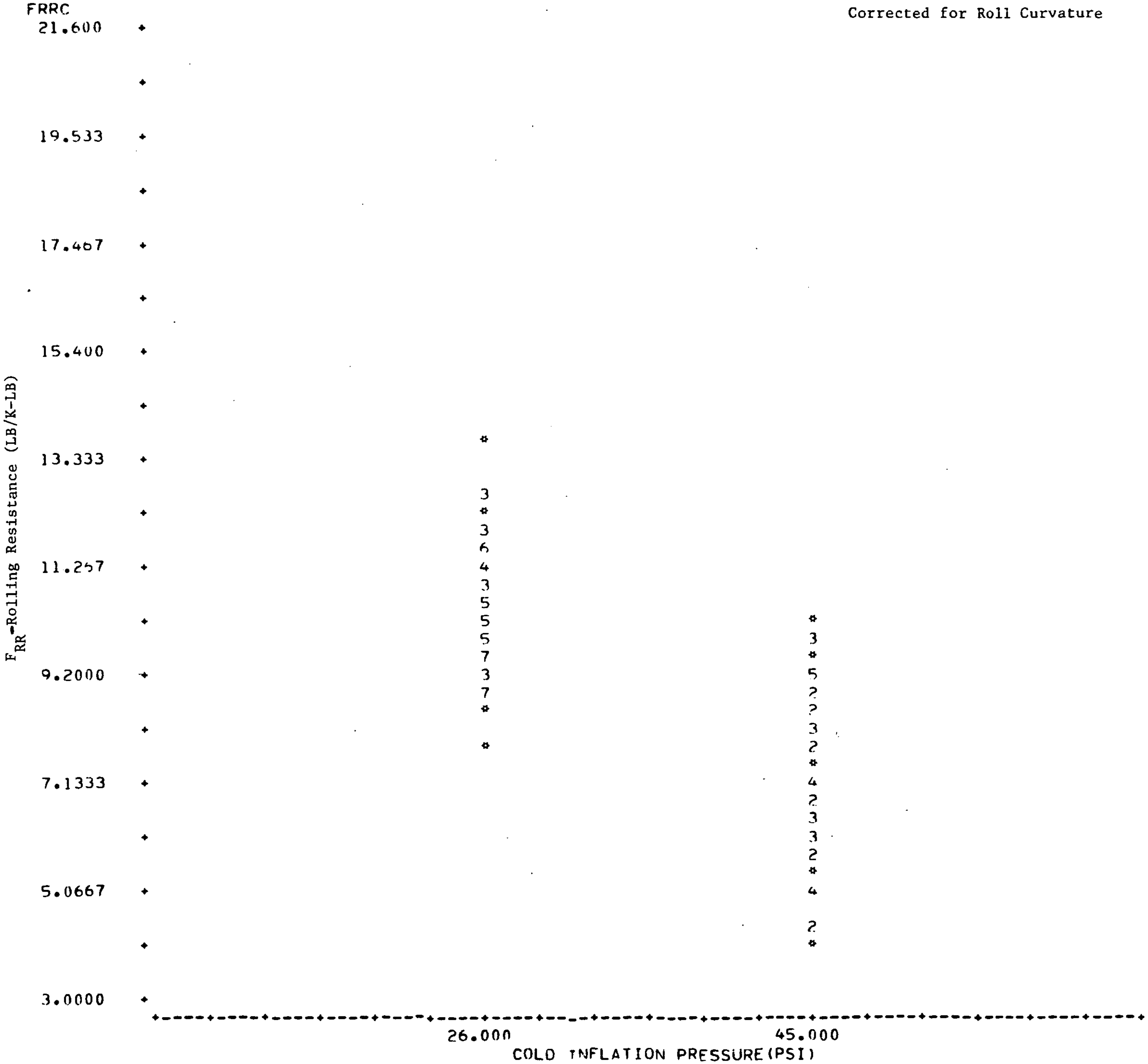


Figure D-14

Tire Rolling Resistance as a Function of Inflation Pressure for Radial Tires

<SCATTER VAR=4;9 CASES=V8:4 INTERVAL=(3.0,21.6):(7.64)>

SCATTER PLOT CASES=TYPE:BIASBE
N= 28 OUT OF 28 4.FRRC VS. 9.PSI

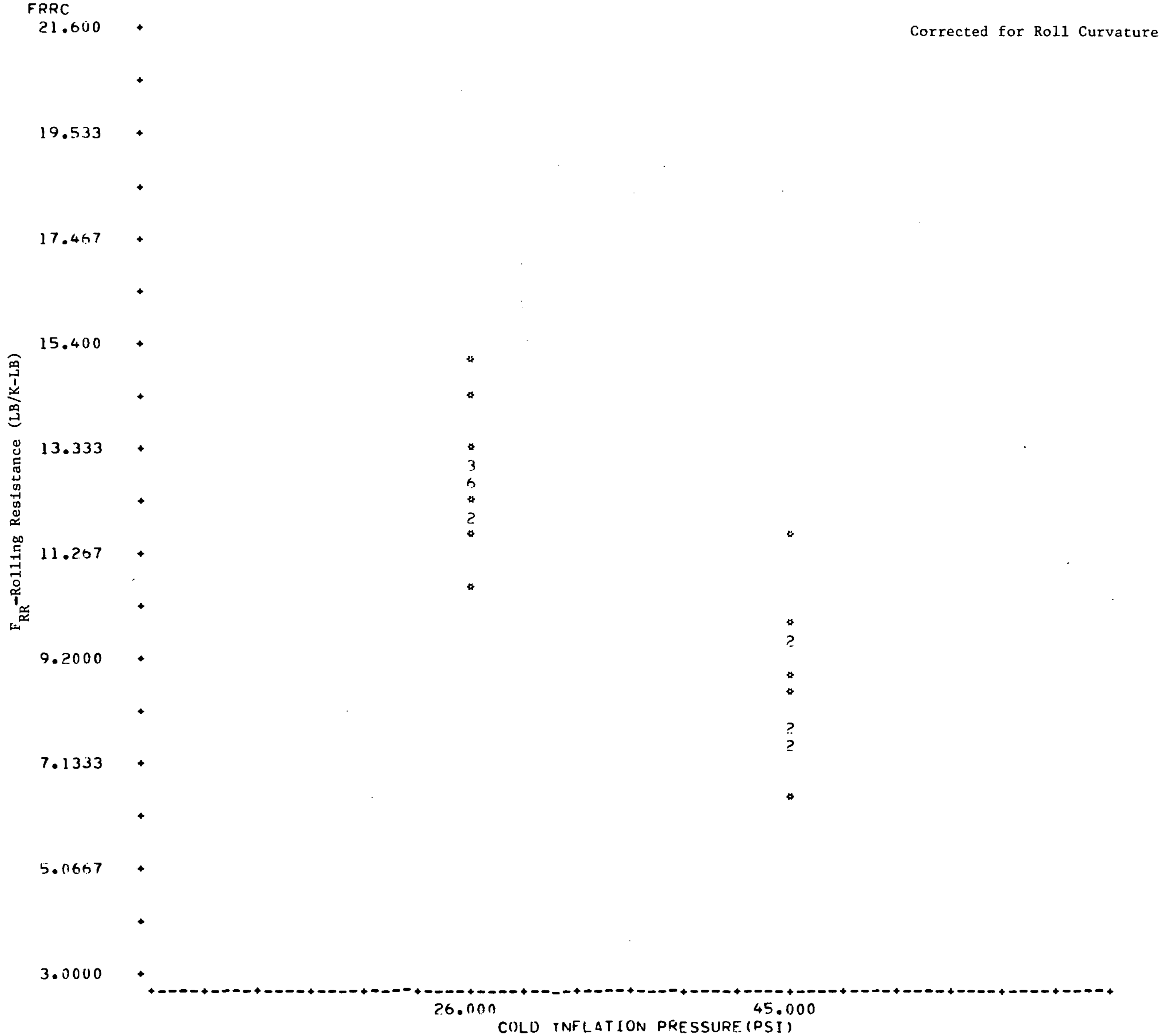


Figure D-15

Tire Rolling Resistance as a Function of Inflation Pressure for Bias Belted Tires

<SCATTER VAR=4;9 CASES=V8:5 INTERVAL=(3.0,21.6);(7,64)>

SCATTER PLOT CASES=TYPE:BIAS
N= 24 OUT OF 24 4.FRRC VS. 9.PSI

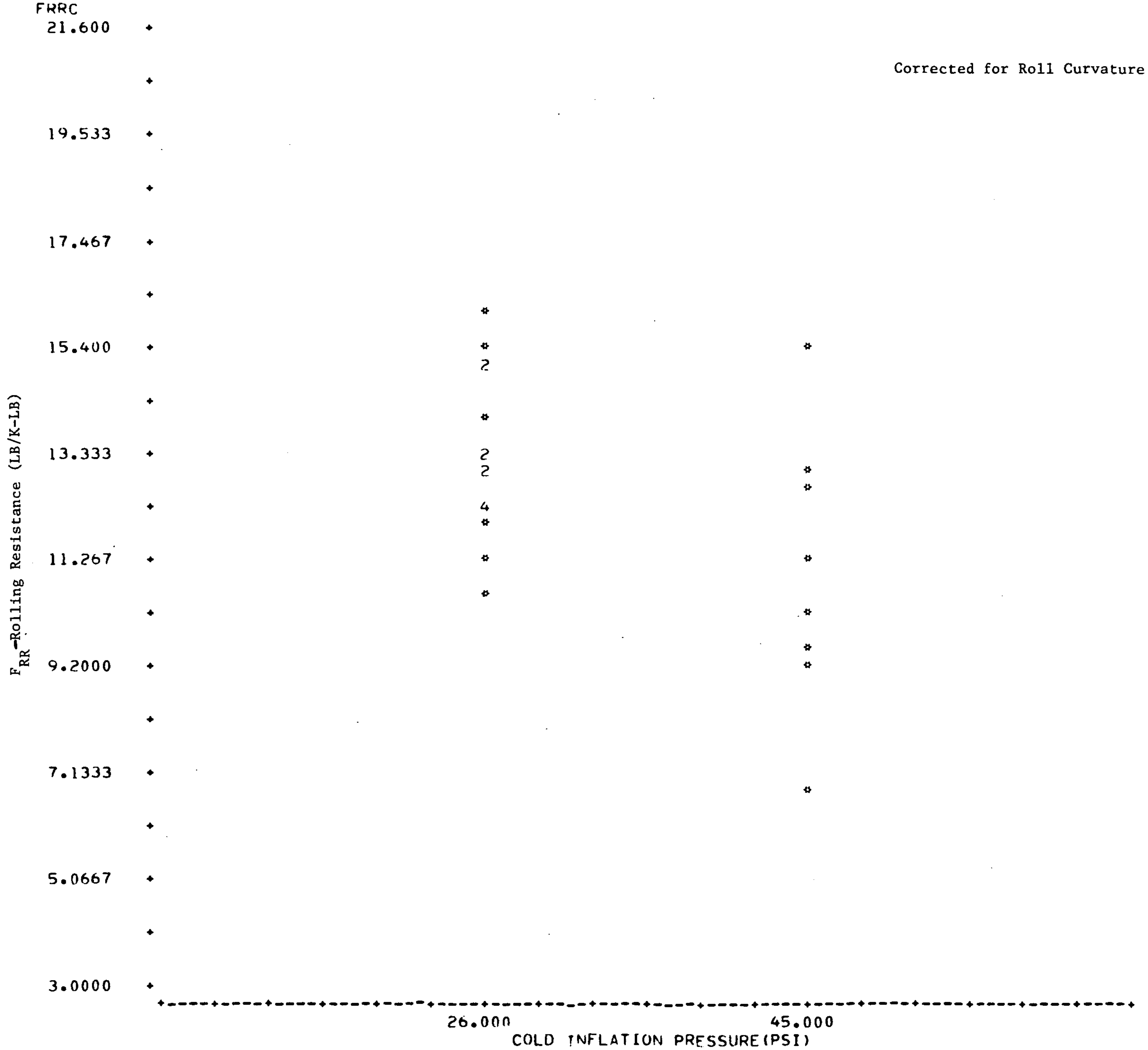


Figure D-16
Tire Rolling Resistance as a Function of Inflation Pressure for Bias Ply Tires

<SCATTER BYSTRATA VAR=4;9 CASES=V8:3 STRAT=V7 INTERVAL=(3.0,21.6);(7,64)>

SCATTER PLOT <13> SI E:13 CASES=TYPE:3
N= 15 OUT OF 15 4.FRRC VS. 9.PSI

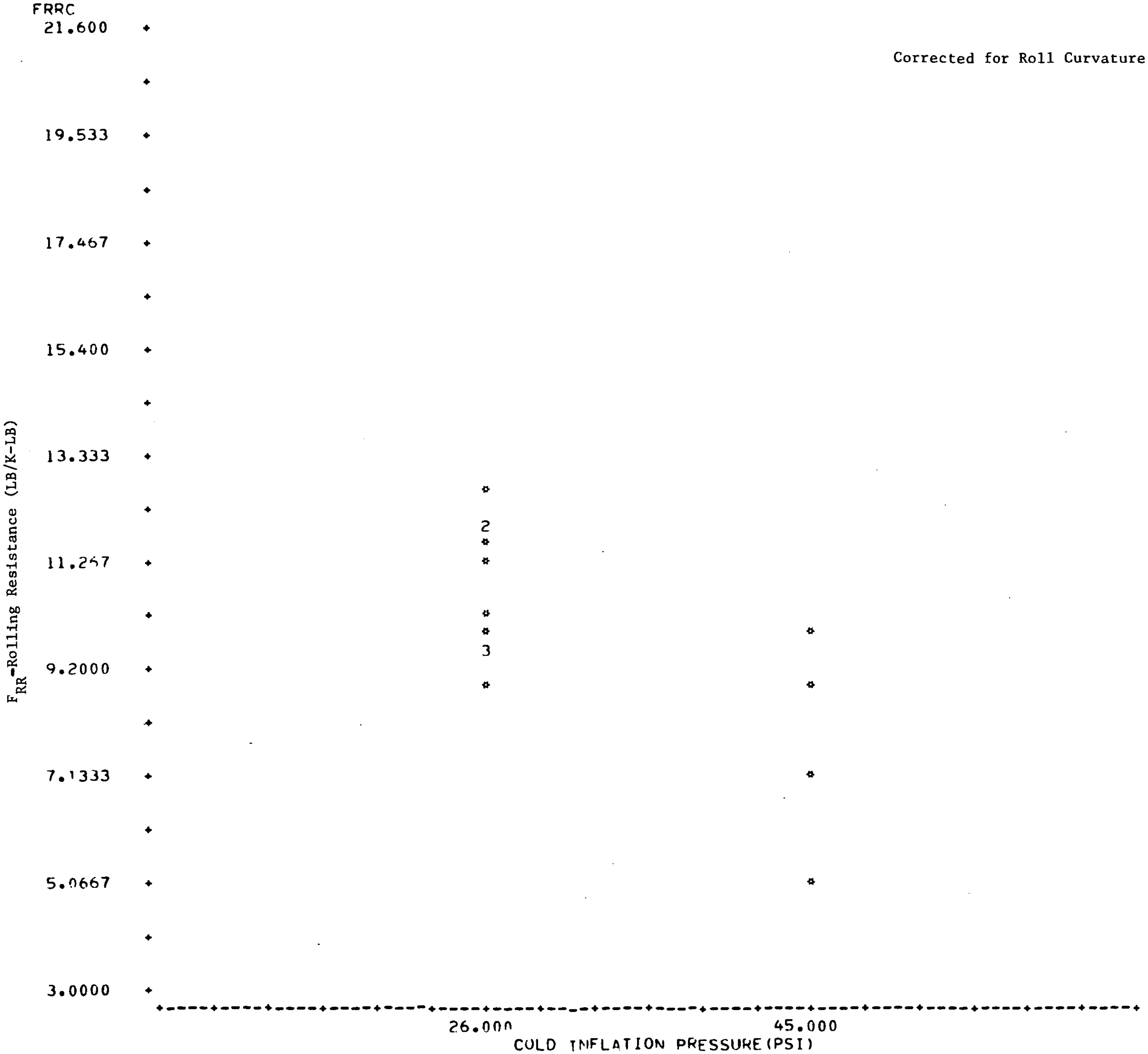


Figure D-17
Tire Rolling Resistance as a Function of Inflation Pressure for 13" Radial Tires

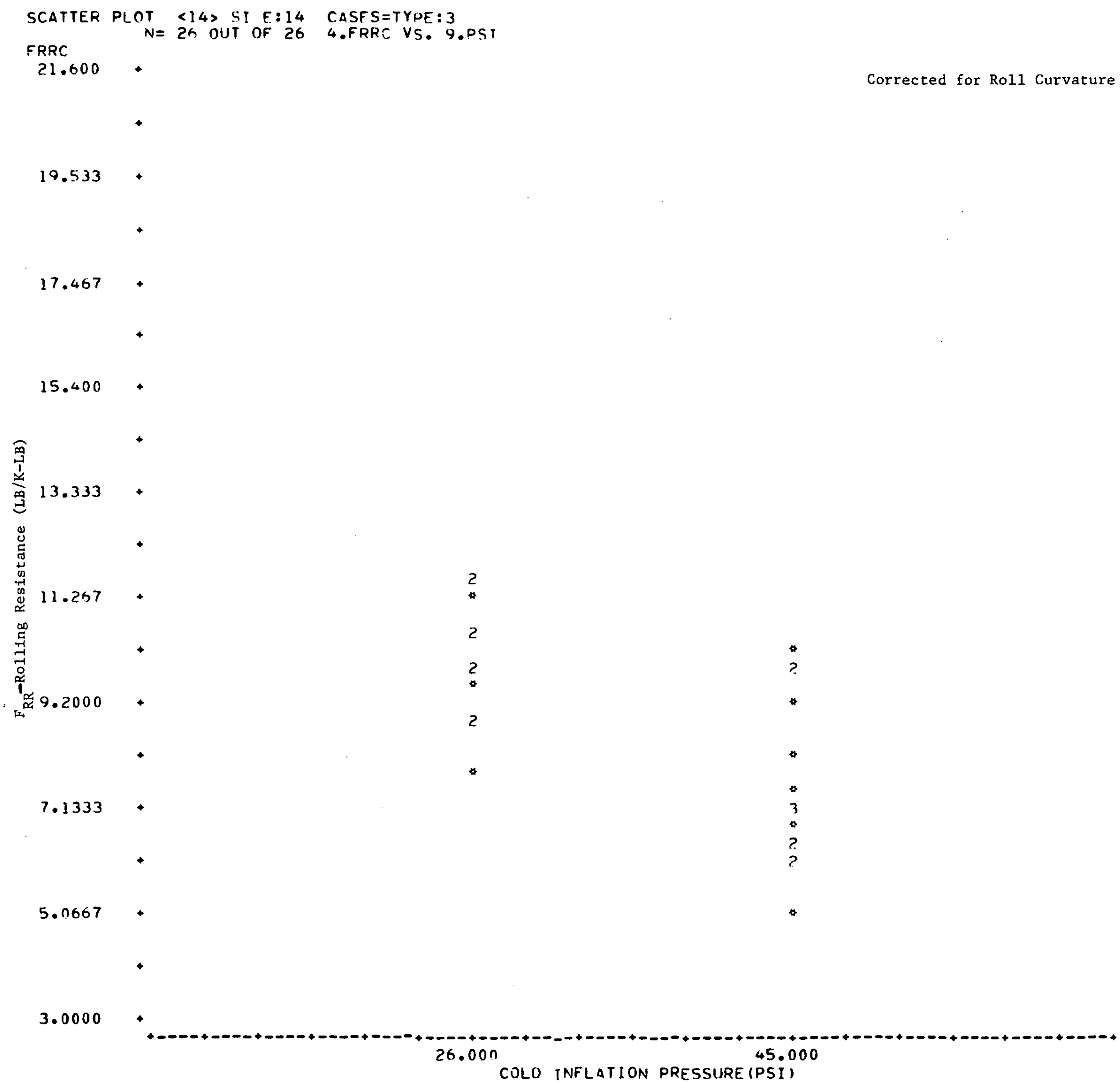


Figure D-18
Tire Rolling Resistance as a Function of Inflation Pressure for 14" Radial Tires

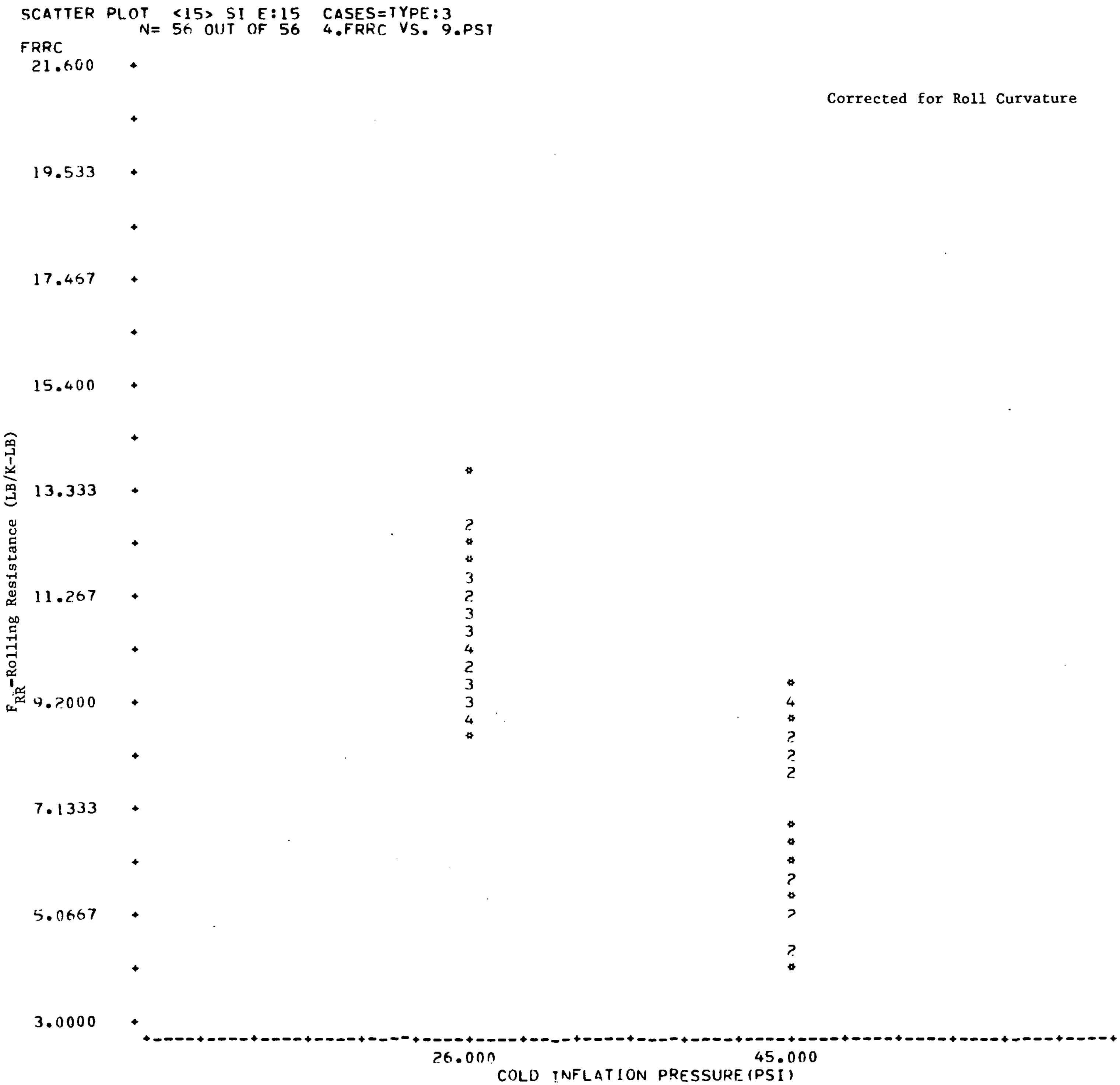


Figure D- 19
Tire Rolling Resistance as a Function of Inflation Pressure for 15" Radial Tires

<SCATTER HYSTRATA VAR=4;9 CASES=V8:4 STRAT=V7 INTERVAL=(3.0,21.6);(7.64)>

SCATTER PLOT <13> SI E:13 CASES=TYPE:BIASBE
N= 3 OUT OF 3 4.FRRC VS. 9.PSI

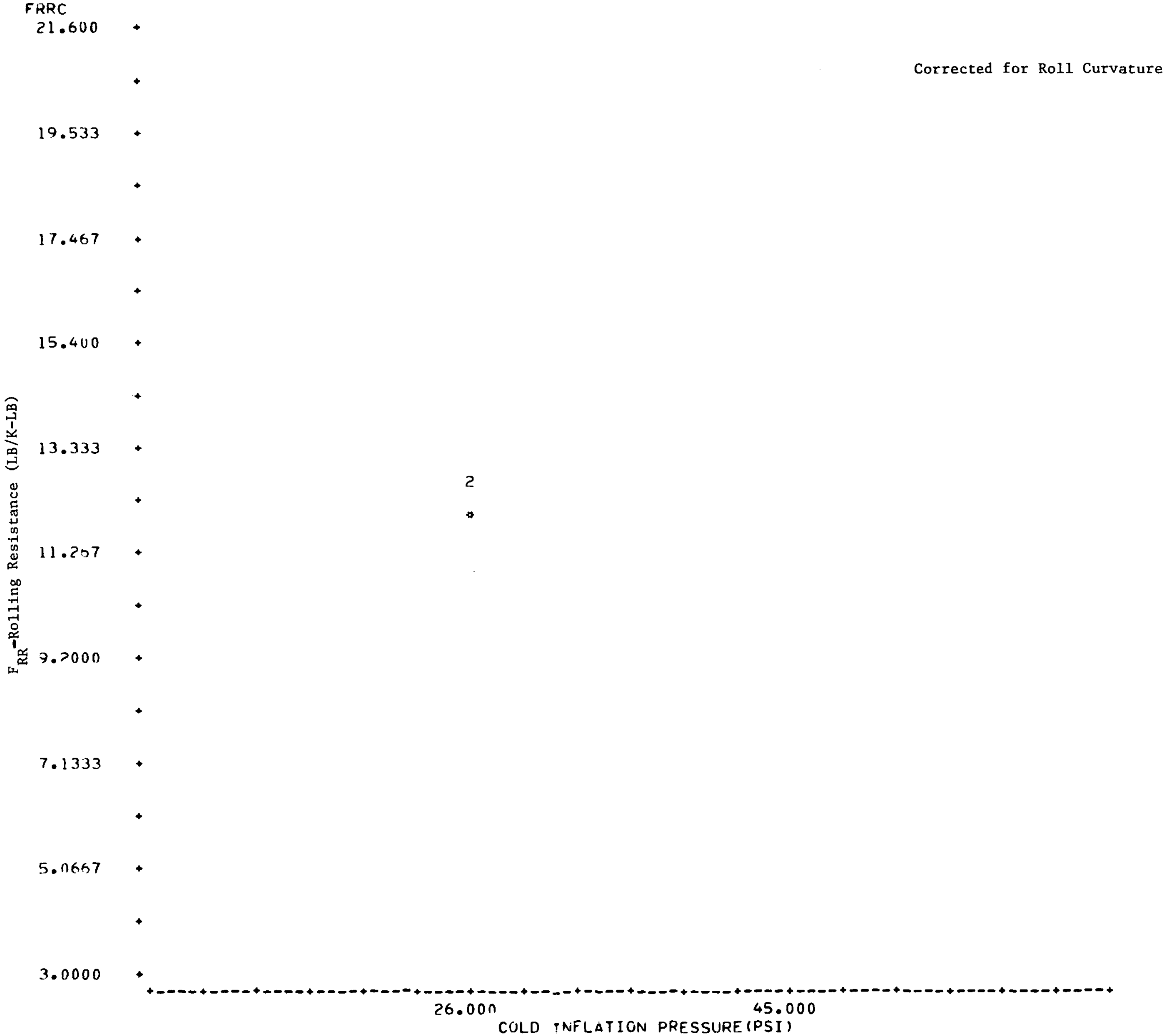


Figure D-20

Tire Rolling Resistance as a Function of Inflation Pressure for 13" Bias Belted Tires

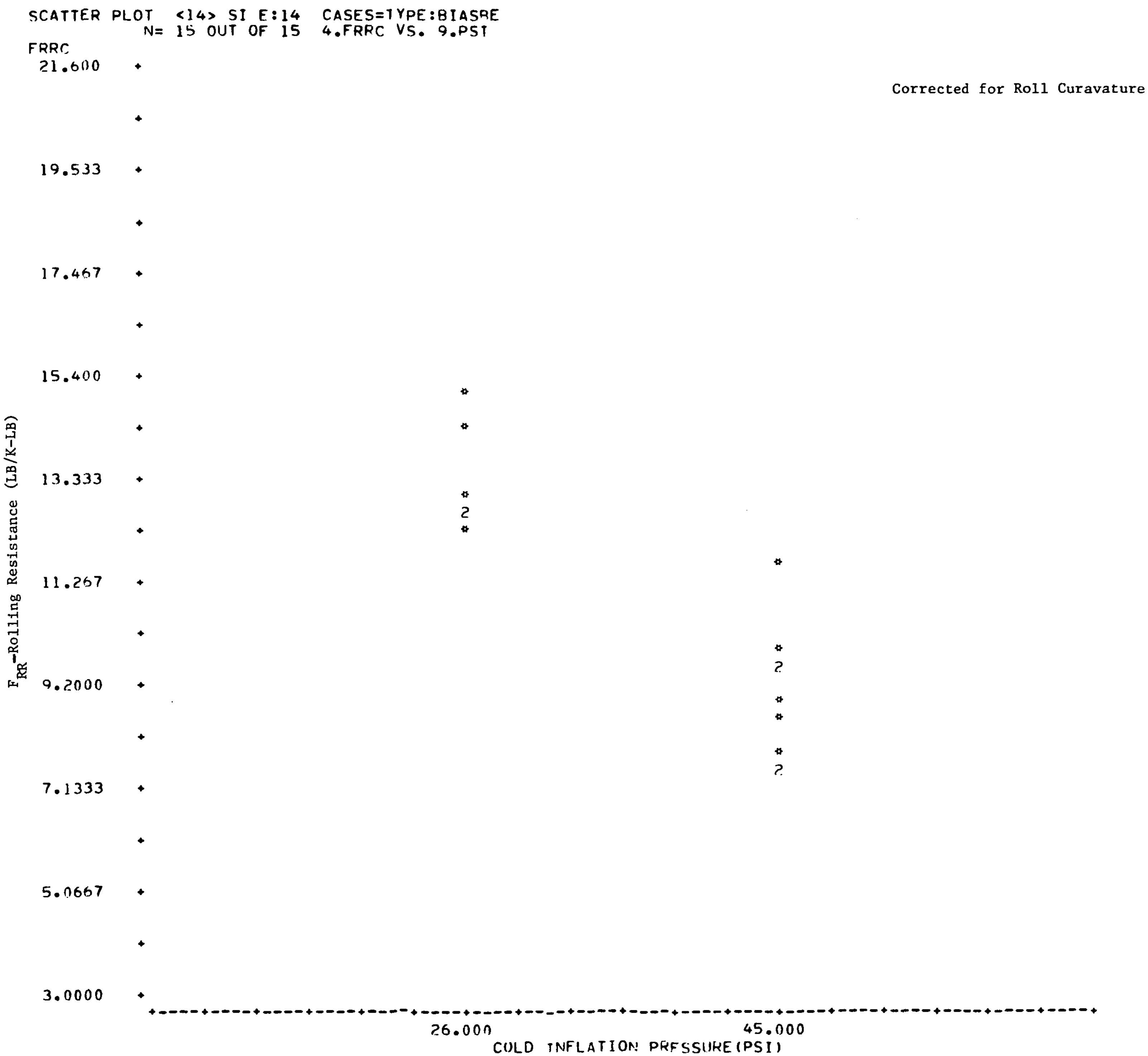


Figure D- 21

Tire Rolling Resistance as a Function of Inflation Pressure for 14" Bias Belted Tires

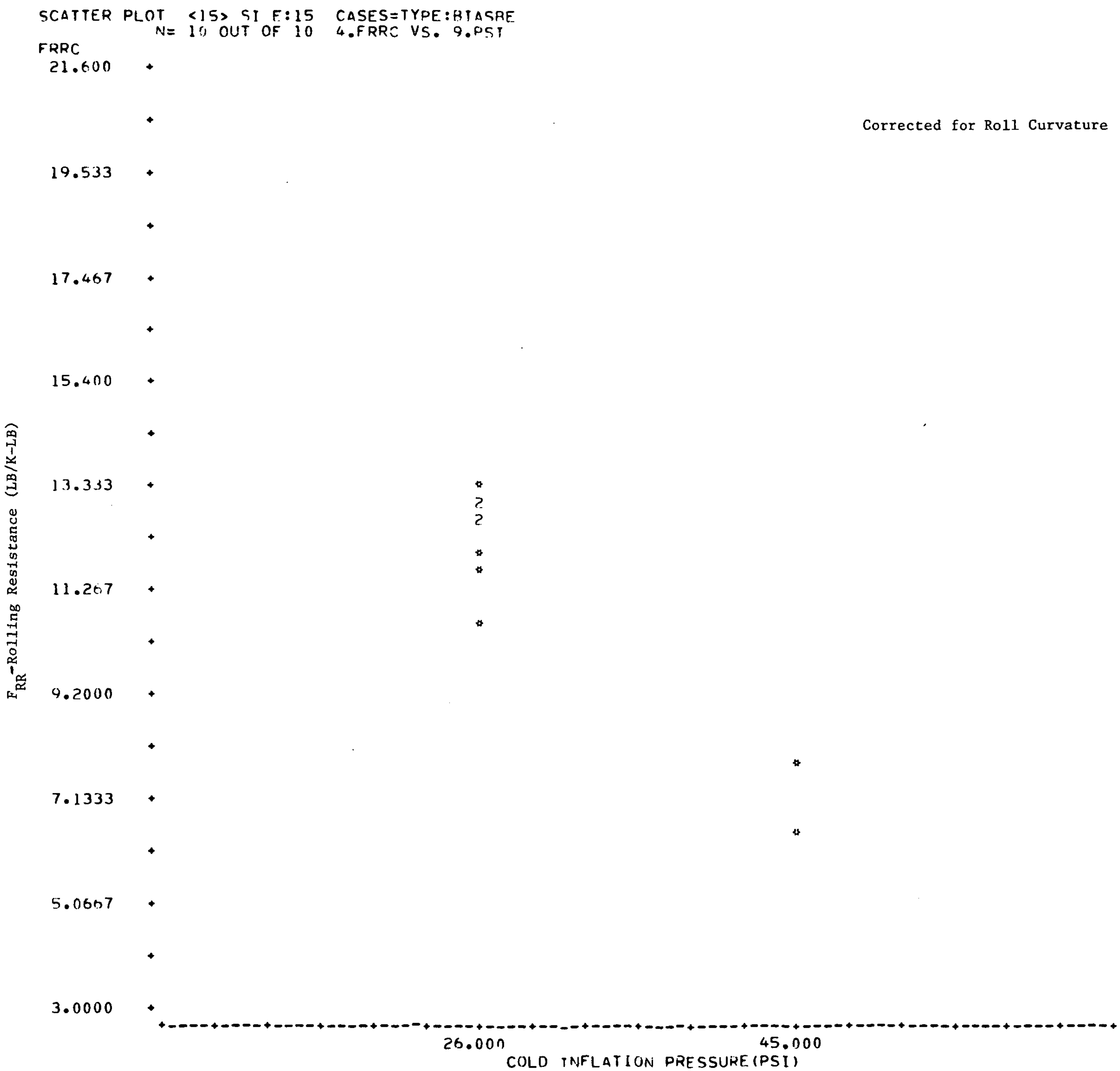


Figure D-22

Tire Rolling Resistance as a Function of Inflation Pressure for 15" Bias Belted Tires

<SCATTER BYSTRATA VAR=4;9 CASES=V8:5 STRAT=V7 INTERVAL=(3.0,21.6);(7.64)>

SCATTER PLOT <13> SI E:13 CASES=TYPE:BIAS
N= 12 OUT OF 12 4.FRRC VS. 9.PSI

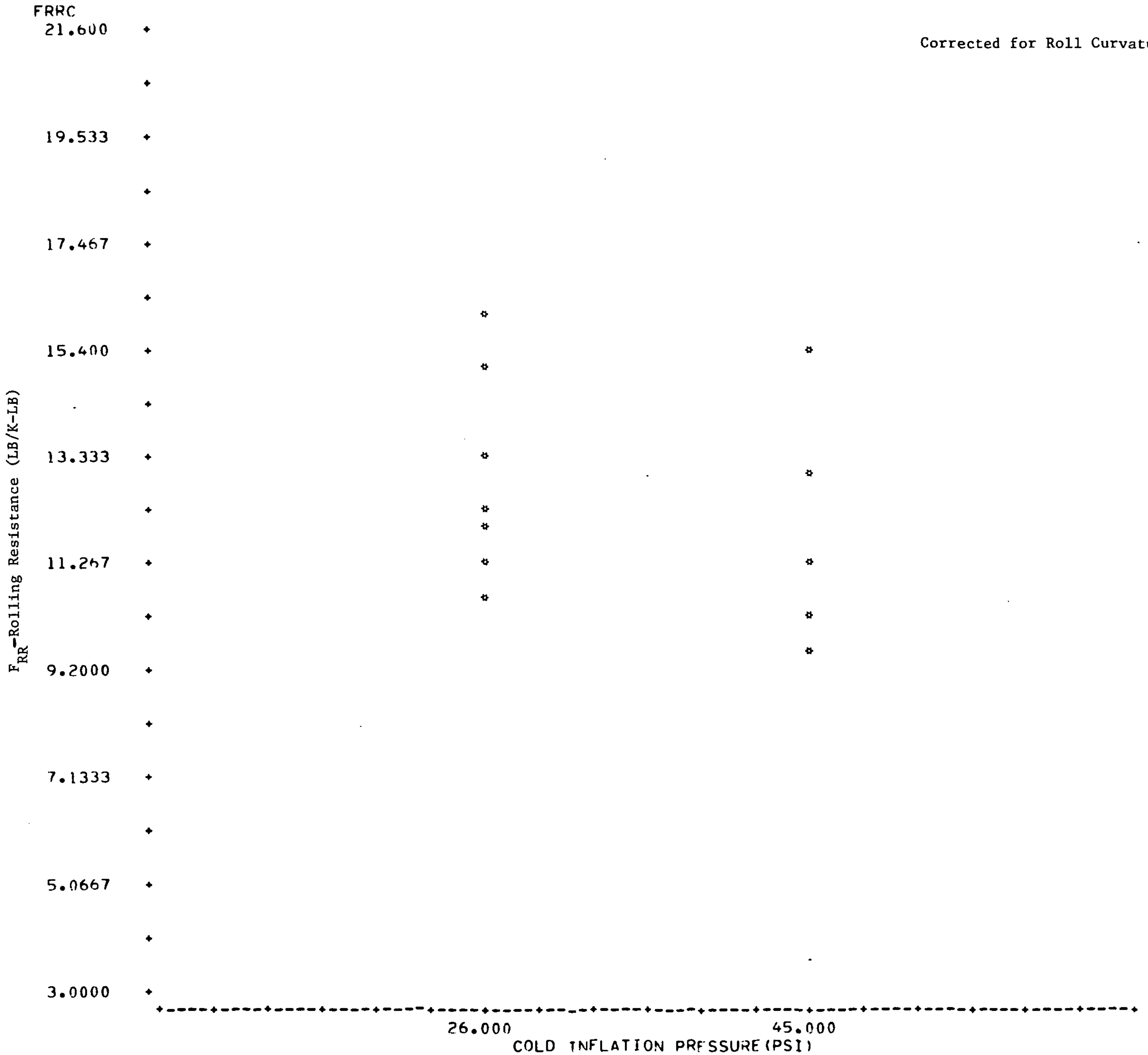
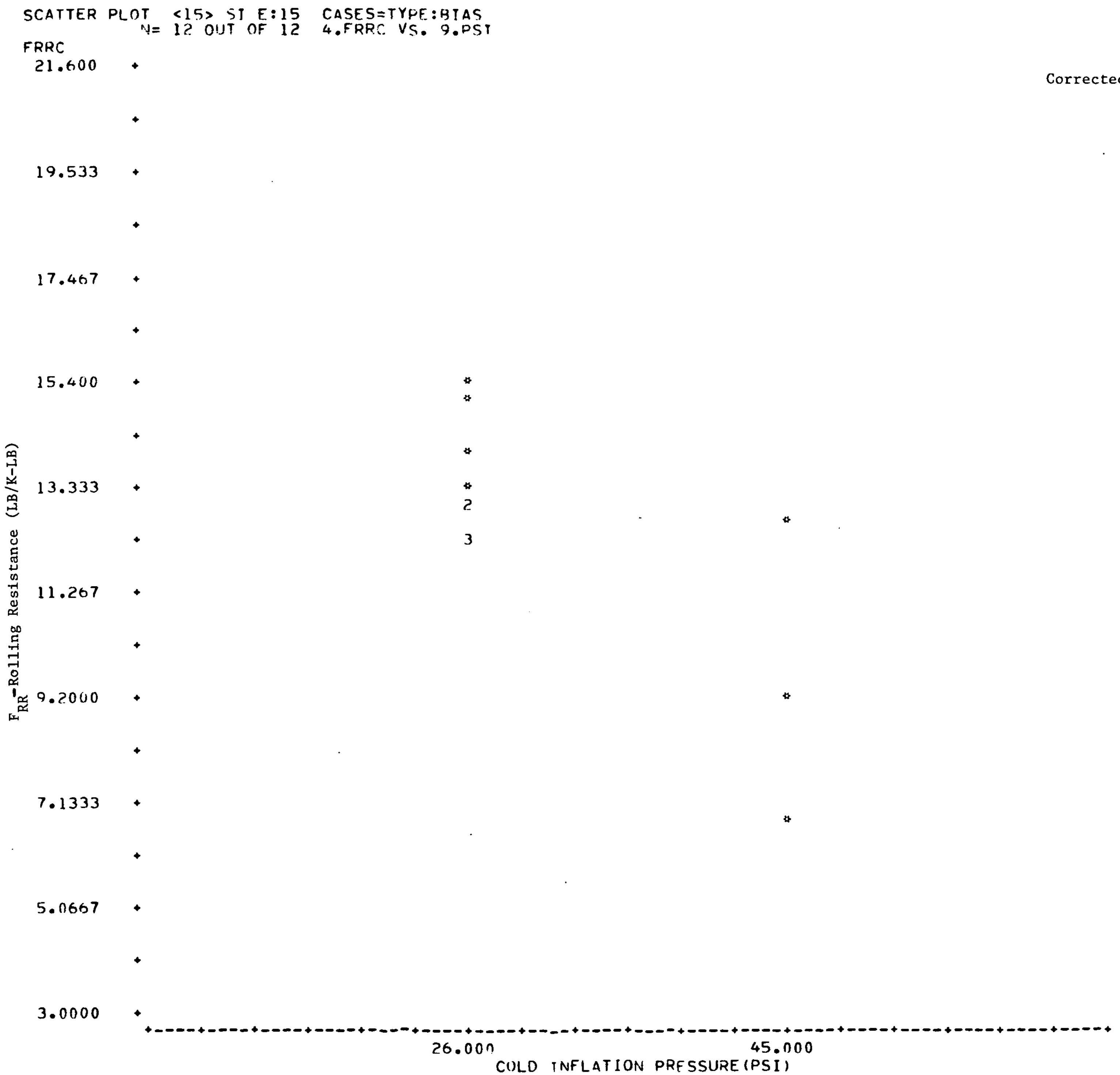


Figure D- 23

Tire Rolling Resistance as a Function of Inflation Pressure for 13" Bias Ply Tires



Corrected for Roll Curvature

Figure D- 24

Tire Rolling Resistance as a Function of Inflation Pressure for 15" Bias Ply Tires