4

Tires - Part Three

A First Look at Tire Data

(*It's just not this simple!)*

Testing and the Race Engineer - The development of test procedures, the running of those tests, the data analysis of the information gleaned from those tests, and, most importantly, the use of that material to make the car faster and more consistent is what the race engineers' job is all about.

The following section is a very brief look at some of the tests that Chapters 20 and 21 will introduce and which Books Two through Four will discuss in considerable detail.

Team Generated Test Analysis - It is in the days and weeks after a series of successful test days that the all so important scenarios can begin to be developed. It is at this time that the race engineer is able to pose a series of questions and go looking for the answers in the analyzed and sorted test data. If the tests were carefully designed, and, during testing, things went according to plan, most of the answers the tests were developed to find will be forthcoming. Are you kidding? Tests never go as planned!

- There are three types of questions:
    1. What happens when?
        - RF spring is changed to ...….from base
        - LR shim stack is changed from .....to .....
        - LF psi is increased 1 lb from base
    2. How can the following happen?
        - get the inside front tire to run hotter
        - get the outside front tire to run cooler
        - get the right rear tire on an oval car to run cooler
        - improve lateral force during braking
        - reduce lateral forces during acceleration
    3. The Whys
        - Why does increased steady state speed reduce cornering performance?
        - Why does increased tire temperature reduce cornering performance?

Tire Temperature Measurement - Accurate measurements of a tire's surface temperature changes can only be accomplished using real time infrared temperature devices plugged into a data system. Collection and studying of real time temperature data is an absolute must if the engineer wants to truly understand tire performance. Beyond the basic data system, the next thing to purchase is infrared tire sensors. Using infrared sensors at the front and rear of the tire, instead of the usual rear location only, reveals how quickly the tire tread heats and cools during each revolution. Don't use a handheld infrared gun to measure at rest tires because the readings you get will be from the very outer tread surface only and this information is not that useful once the chassis is at rest.

If a pyrometer is used (at rest chassis), make sure you are measuring the cord temperature and not the tread surface temperature. A tire's surface temperature, when at rest, is not a good indication of on track tire temperatures. The pyrometer, if very carefully and thoughtfully used, can help the engineer analyze camber, toe and air pressure changes, but in many cases, the team only uses a pyrometer because all the other teams are using one. It is very easy to go down the wrong road with erroneous pyrometer results. Small changes in air pressure are far more accurate when trying to determine performance trends. However, if the team does not have access to infrared data, long live the pyrometer.

Tire temperature and small air pressure change analysis are two of the most important tools the race engineer has.

Table 4-1 is an example of just one of the many tests needed to develop tire set up scenarios (see Chapter 18). This type of test needs to be run using 1 to 4 hot laps and 10 hot lap runs in order to develop short and long run strategies. You don't need to run 50 lap tests in order to develop 50 lap results. It is very important that the car is not changed from its base line setting during tire tests. This is easy to say but not so easy to accomplish due to tire performance degradation as the tire is used.

Table 4-1 Oval Track Tire Testing - Right Rear

Test#_____ Set Up#_____ Turn Radius_____ Average Speed_____ Track Temp. _____ Laps_____ Base RR psi _____								
PSI Increase RR	RR Temp. Increase	RR psi Increase	LR Temp. Increase	LR psi Increase	RF Temp. Increase	RF psi Increase	LF Temp. Increase	LF psi Increase
1 lb.								
2 lb.								
3 lb.								
4 lb.								

Heat Generation - Heat generation of the tread rubber through lateral shearing, slip and squirm is a primary cause of performance falloff. Heavy racecars such as stock cars are much more susceptible to heat generation than lighter racecars.

- Examples of Possible Test Scenarios:
  - 1 degree increase in camber:
    - effect on lateral acceleration forces - by (x) plus or minus amount
    - effect on heat generation - by (x) plus or minus amount
  - 1 psi decrease in tire pressure:
    - effect on lateral acceleration forces - by (x) plus or minus amount

- effect on heat generation - by (x) plus or minus amount

Table 4-2

Effect of tire pressure change on lateral force versus heat generation		
Test #_____ Tire #_____ Date_____ Tested By_____ Car_____ Driver_____ Static Load_____		
Notes:		
psi	Gain/Loss Lateral Force	Gain /Loss Heat Gen.

Table 4-3 outlines various combinations of steer angle, speed and turn radius tests, for example, steering angle and speed with turn radius held constant or steering angle and radius with speed held constant. This type of test is a must, and, nine times out of ten, after the test results are carefully examined, significant and wide ranging improvements in track performance will be found. This type of test needs to be run on a test pad if the car is not equipped with infrared heat sensors. If the car is equipped with infrared sensors, the tests can be accomplished at each individual corner of either an oval or road course.

Table 4-3

Variables			**Results**											
Steering Angle	Speed	Turn Radius	(-) Inline Acc	(+) Inline Acc.	Lateral Force	Total G	RF psi	RF temp	LF psi	LF temp	RR psi	RR temp	LR psi	LR temp
Data Point - From ___To ___														
Data Point - From ___To ___														
Data Point - From ___To ___														
Data Point - From ___To ___														

Table 4-4 is the first of many variables from the previous example. It combines Ackerman and camber with steer angle rather than speed and radius. These types of tests are not only invaluable but it is just about impossible to fully develop the car without them. Further examples are shown in tables 4-4 / 4-7. The major problem in designing this type of test is that there are literally thousands of possibilities - so much to do and never enough time or money to do them all. The success or failure of a test date is more often than not a product of how well the test sequence is thought out and developed. Having access to an endless number of data channels is somewhat of a mixed blessing. The more channels you have, the more you can test but it will take exponentially longer to analyze the data.

Table 4-4 - Various combinations of steer angle, Ackerman and camber

Variables			**Results**											
Steering Angle	Ack.	Camber	(-) Inline Acc	(+) Inline Acc.	Lateral Force	Total G	RF psi	RF temp	LF psi	LF temp	RR psi	RR temp	LR psi	LR temp
Data Point - From ___To ___														
Data Point - From ___To ___														
Data Point - From ___To ___														
Data Point - From ___To ___														

Table 4-5 - Various combinations of steer angle, speed and camber

Variables			**Results**											
Steering Angle	Speed	Camber	(-) Inline Acc	(+) Inline Acc.	Lateral Force	Total G	RF psi	RF temp	LF psi	LF temp	RR psi	RR temp	LR psi	LR temp
Data Point - From ___To ___														
Data Point - From ___To ___														
Data Point - From ___To ___														
Data Point - From ___To ___														

Table 4-6 - Effects of Aero Balance on Lateral Force Versus Heat Generation

Test#_____ Tire#_____ Date_____ Tested By_____ Conditions_____
Car_____ Driver_____ Static Load_____ Air Density _____

Radius_____ Speed_____ Set Up #_____ Base psi_____ Ride #_____ Pitch # _____
Base Setting: Front Element R____/____ Flap_____ Front Element L____/____ Flap____
R Wicker_____ Flap____ L Wicker_____ Flap_____ End Plate_____ Flaps____/____
Rear Lower Element_____/_____ Flap_____
Rear Upper element_____/_____ Flap_____ End Plate_____ Flaps_____/_____

Notes:

Corner	Aero Change	Dynamic Load	Gain/Loss Lateral Force	Gain/Loss Heat Gen	Gain/Loss psi	Gain/Loss Acceleration
LF						
RF						
LR						
RR						

Table 4-7 - Effects of Mass Change on Lateral Force Versus Heat Generation

Test#____ Tire#_____ Date_____ Tested By_____ Ambient Conditions _____ Car_____ Driver_____ Track _____ Track conditions _____ Laps on Tire#_____						
Unloaded Radius_____ Loaded Radius_____ Base Loads: RF_____ LF_____RR_____ LR_____						
Notes:						
Load Change	Gain/Loss Lateral Force	Gain/Loss Heat Gen.	Dynamic Load RF	Dynamic Load LF	Dynamic Load RR	Dynamic Load LR

Analyzing the Data - Once the tests have been run, the engineer needs to put the data into usable table and graph formats. See Chapter 19 for an explanation of how these graphs are used to develop set up scenarios. The data from these types of tests is then added to an overall tire performance formula. Thus, we have the beginnings of race car simulation.

Changes in tire temperature (outer and inner tread surface temperature and carcass temperature) along with changes in psi are the two most useful constants to test all other aspects of tire performance against. Changes in psi and temperature are normally very closely linked. For example, an increase in running temperature will also see an increase in running psi. A change in psi will affect the contact patch size while a change in temperature will affect the tire's tread coefficient of friction performance. Once a team knows the temperature and psi trends and changes as the result of different tests, those results can be factored into the master tire performance tables, graphs and charts. Figure 4-1 shows a general trend of temperature versus steer angle variables. Notice that the plot is not linear and that the increase in temperature for this particular tire with this particular set up falls off between 4 and 5 degrees of steer, indicating a low sliding coefficient. Each tire type, set up and driving style will have its own individual set of parameters even if tested under the same conditions and on the same track.

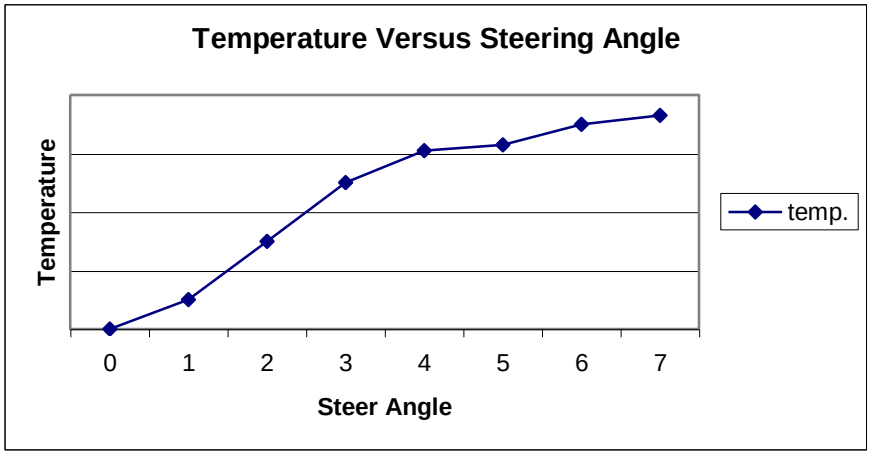


Figure 4-1

Figure 4-2 illustrates a temperature versus distance traveled plot. For this individual tire, set up and driving style, the temperature increases much faster between 1 and 5 laps with the rate of increase falling dramatically after 5 laps. A different tire, set up or driving style could provide just the opposite data. Don't take anything for granted because even a small change in camber or caster can dramatically affect the outcome of a test. At the beginning stages of tire analysis, trends are often more important to discern than actual numbers.

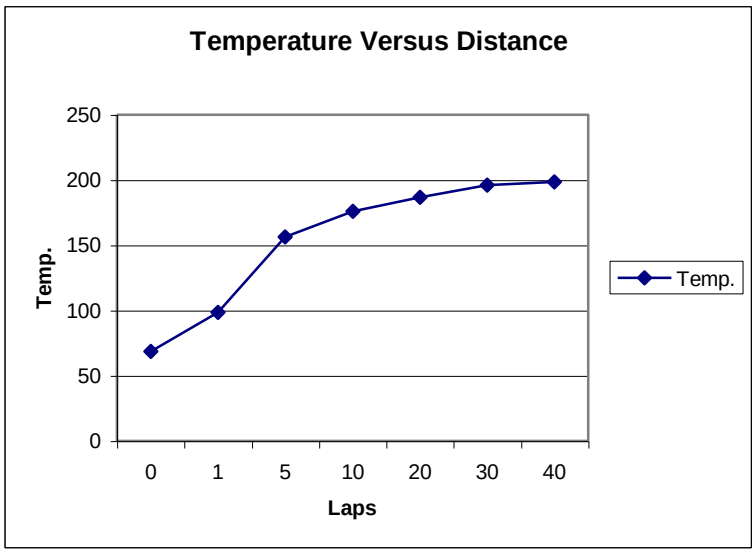


Figure 4-2 – One lap equals ½ mile

Tire temperature normally increases with an increase in lateral force but not always in a purely linear manner - Figure 4-4

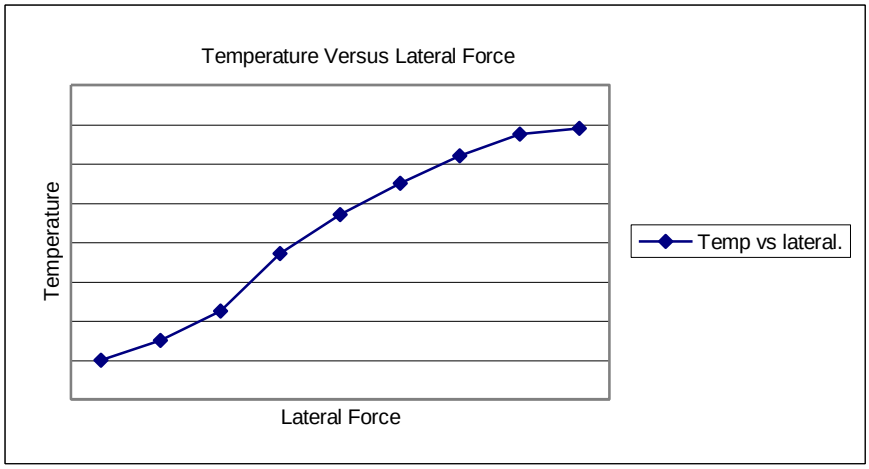


Figure 4-3

Tire temperature also normally increases with an increase in vertical load, but, again, not always in a pure linear manner - Figure 4-4. Always look for similarities and cross links between the different tests. *Key tuning tool*.

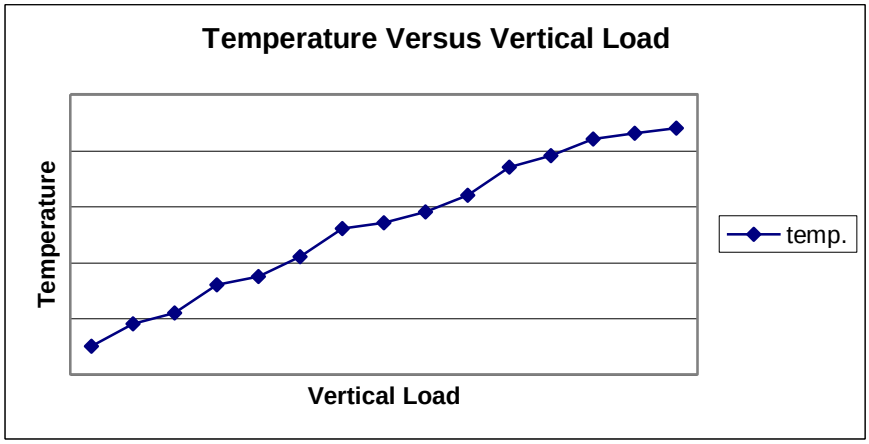


Figure 4-4

When graphs are presented in normalized terms, it is often easy to think two graphs have similar scales, when, in fact, they are quite different, as shown in Figure 4-5 where the lateral and vertical vs temp graphs from Figures 4-3 & 4-4 are combined.

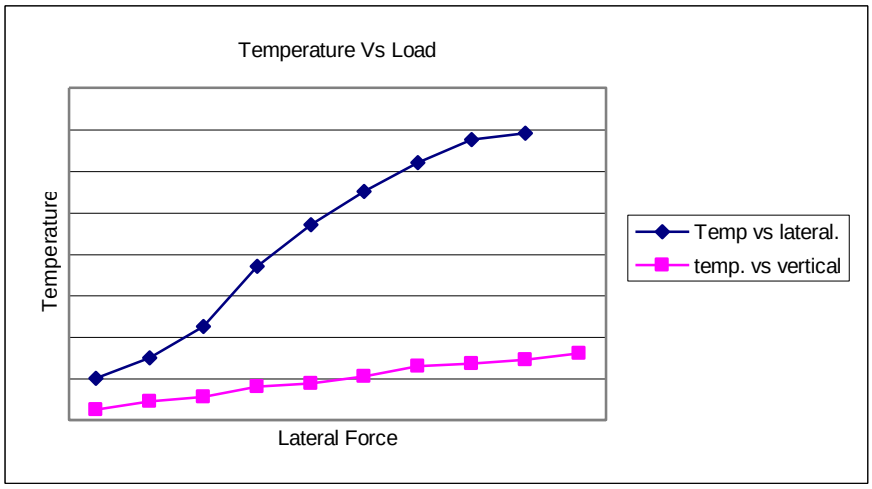


Figure 4-5

Figure 4-6 represents the temperature change between a chassis' four corners versus the number of laps run. In this case, none of the corners are represented by a purely straight line. The engineer needs to spend time looking at the different graphs and then, most importantly, determine what caused the temperature differences. *Key tuning tool*.

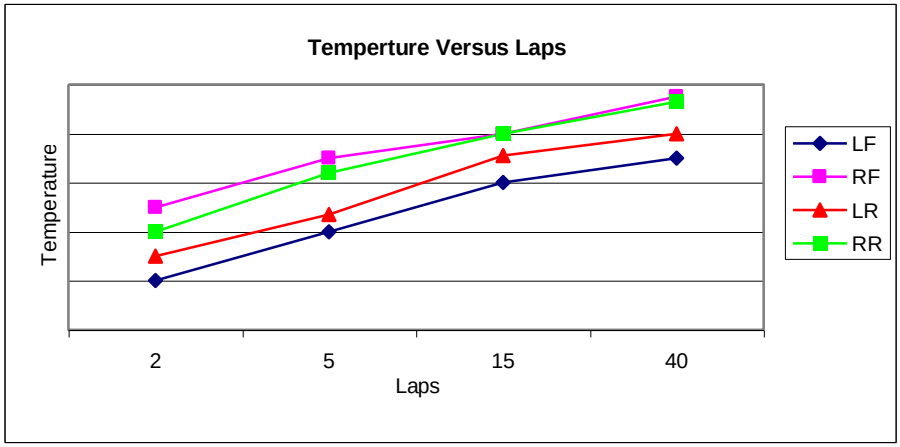


Figure 4-6

Figure 4-7 illustrates right front temperature changes and trends versus combined Ackerman and steer angle. It is interesting to note that with this particular test, 3 degrees of Ackerman produced the lowest heat gradient (inside tire is turned 3 degrees more than the outside tire). *Key tuning tool*.

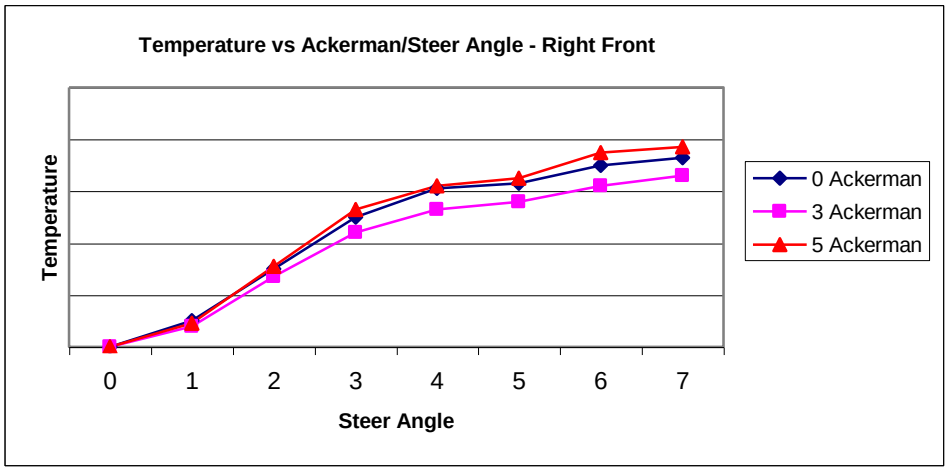


Figure 4-7

Figure 4-8 show a graph of temperature versus tire prerun pressure settings. Notice that the 15 psi setting produced the highest temperature readings during the initial laps while the 40 psi setting produced the highest temperature readings later on in the run.

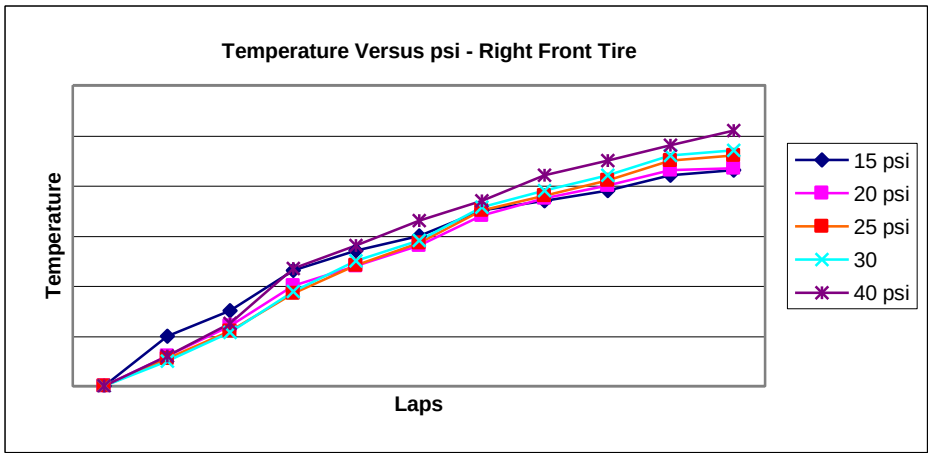


Figure 4-8

Temperature versus coefficient of friction graphs are of key importance when determining what set up to run on a car - Figure 4-9. The race engineer needs to know at what temperature range the tires produce the highest coefficients of friction. The chassis set up is then designed for maximum mean performance throughout the run, or, conversely, for a particular time within the run. As discussed later, the engineer also needs to determine optimum temperature versus rate of tire performance degradation.

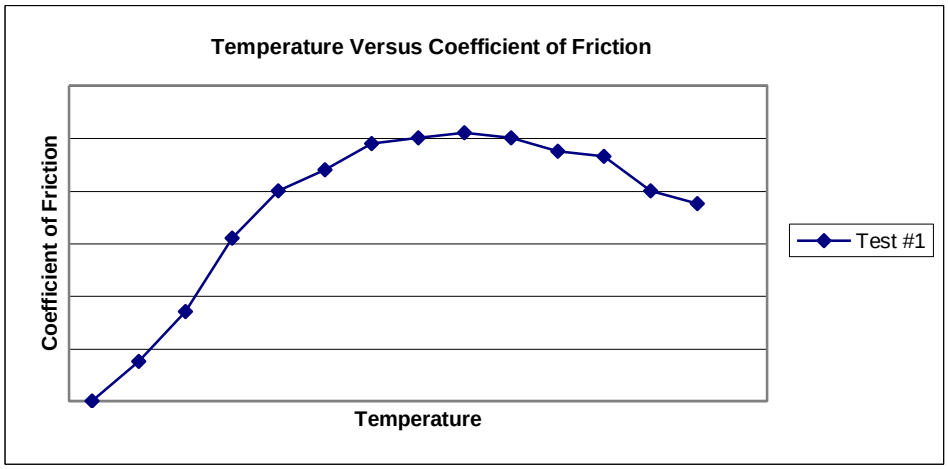


Figure 4-9

Loaded Tire Radius - It is important, as will be discussed in subsequent chapters, for the race engineer to know what the **loaded** radii of the tires are, the wheel rate and the rolling resistance for any particular tire pressure and camber setting at the various shear angles. Depending on what tire plan the team is on, this type of information may be obtained from the tire company; otherwise, the team will need to develop on track tests to establish this type of information. The race engineer should also make a simple press jig to map out the tire's static spring rate and loaded radius - Figures 4-10 / 4-12 What this test jig will not provide is radius versus speed which must be obtained from the tire companies or through data acquisition using travel sensors, infrared ride height sensors and/or high speed, high quality digital cameras capable of measuring the tire's dynamic radius. Information regarding the various tire parameters will be discussed in some detail in the remaining four books. Most radial tires show little radius change throughout the speed variables while bias ply tires, depending on the design, may show considerable radius change.

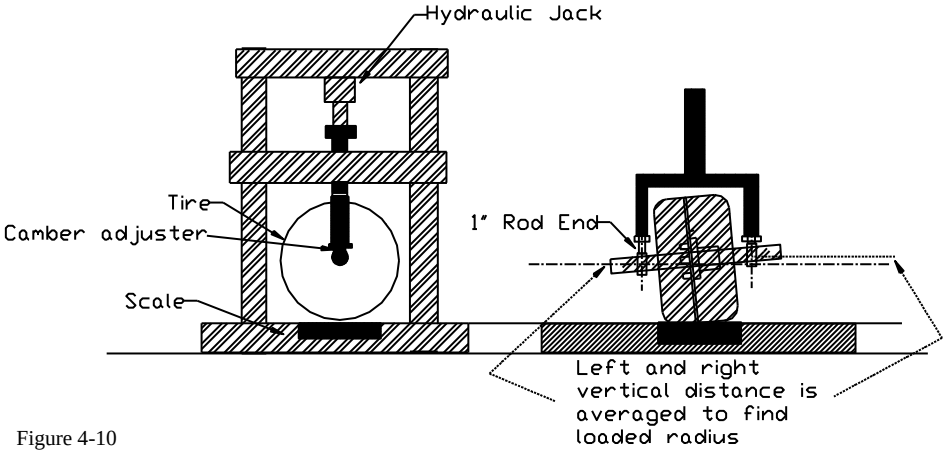


Figure 4-10



Figure 4-11

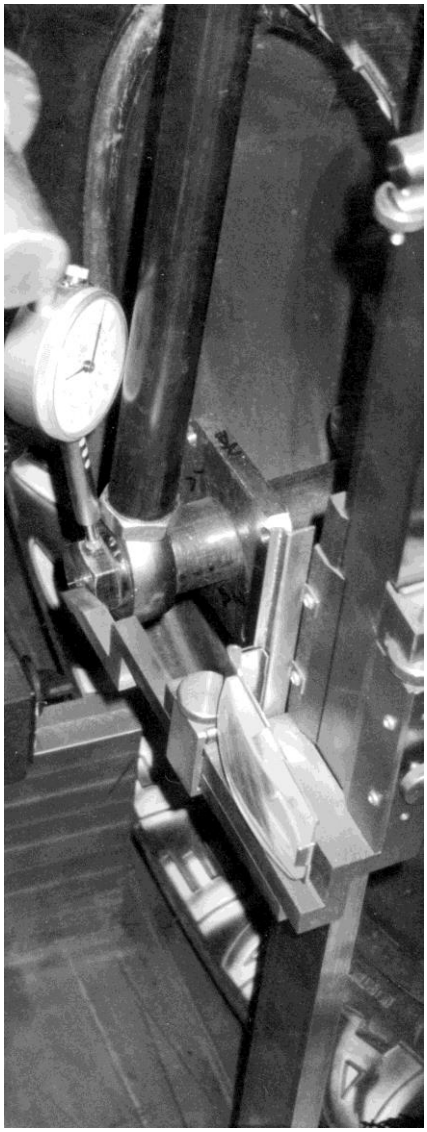


Figure 4-12

The following tables are a small representation of data collected from various tires using the test jig in Figure 4-10. As in every type of test, I have never found the results to be quite what I expected and they are certainly never cut and dried. Books Three and Four devote considerable space to interpreting this type of data, and, particularly, how it can be successfully used on the track. Track performance is always the bottom line. Don't get caught up in the process of meaningless time-wasting details.

Once you have established the amount the radius increases or decreases during a number of dynamic datum conditions, the static to dynamic changes are normally quite straightforward and involve mostly linear solutions. Whenever possible, compare tire manufacturer's data with your own. Sooner or later, a good comparison library is going to be very helpful.

Table 4-8 compares changes in contact patch load versus tire psi settings for a preload of 500 lb.

Table 4-8

Tire Spring Rate Tire#_____Test #_____					
Tested By					
Note: Tire preloaded to 500 lb. - Load cell was then zeroed and zeroed again after each test segment.					
psi	1/4" decrease in radius 1/4" Total Load Change lb.	1/4" decrease in radius 1/2" Total Load Change lb.	1/4" decrease in radius 3/4" Total Load Change lb.	Total Load Total Load Change lb.	Average per 1/4" radius change Average Load Change
15	298	270	211	779	259.7
20	356	231	225	812	270.7
25	400	287	272	959	319.7
30	412	360	320	1092	364.0
35	440	370	340	1150	383.3
40	466	366	348	1180	393.3

Tables 4-9 & 4-10 illustrate a change in tire radius versus a change in tire psi. Notice that a lighter preload was less affected by a psi change. This is also the case with increases in shear angle, G forces, speed, etc. *Key tuning tool*.

Table 4-9

Tire Radius Test Tire#_____Test #_____ **Per Change in psi** Date Base psi 15					
Notes: Tire preloaded to 1000 lb. - Load cell was then zeroed and zeroed again after each test segment.					
psi	Load (lb.) Change	Resulting Radius (")	Radius Change (")	Total Change (")	Notes:
15	0	10.980	0.000	0.000	
20	111	11.006	0.026	0.026	
25	141	11.037	0.031	0.057	
30	139	11.056	0.019	0.076	
35	123	11.072	0.016	0.092	
Total	514				
Average	128.5				

Table 4-10

Tire Radius Test Tire#_____Test #_____ **Per Change in psi** Date Base psi 15					
Notes: Tire preloaded to 1500 lb. - Load cell was then zeroed and zeroed again after each test segment.					
psi	Load (lb.) Change	Resulting Radius (“)	Radius Change (“)	Total Change (“)	Notes:
15	0	11.005	0.000	0.000	
20	151	11.020	0.015	0.015	
25	202	11.026	0.006	0.021	
30	178	11.040	0.014	0.035	
35	122	11.069	0.029	0.064	
Total	653				
Average	163.25		0.0160		

Table 4-11 and Figure 4-13 illustrate changes in a tire’s radius due to a change in tire pressure. The fact that the resulting graph is not purely linear is due primarily to tire design and construction.

Table 4-11

Tire Radius Test Tire#_____Test #_____ Base Load _____ Base psi_____ **Per Change in psi** Notes:				
psi	Radius (“)	Radius Change (“)	Running Total (“)	
15	12.75	0.000	0.000	
17	12.77	0.020	0.020	
19	12.785	0.015	0.035	
20	12.795	0.010	0.045	
22	12.806	0.011	0.056	
24	12.82	0.014	0.070	
26	12.84	0.020	0.090	
28	12.873	0.033	0.123	
30	12.889	0.016	0.139	
32	12.905	0.016	0.155	
34	12.910	0.005	0.160	
36	12.930	0.020	0.180	
38	12.939	0.009	0.189	
40	12.955	0.016	0.205	

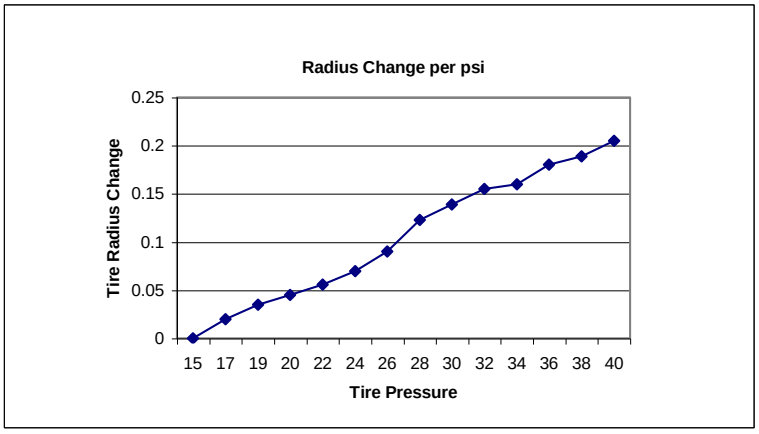


Figure 4-13

Table 4-12 and the graph in Figure 4-14 illustrate load changes at the inside and outside contact patch as the result of differences in camber and psi.

Table 4-12

Camber Tire Test Tire# Test #					
Date Base psi **15**					
Notes: Measurement of individual inside and outside loads at given camber angle					
Load	psi	Inside Load	Outside Load	Difference	Neg. Camber
503	40	267	236	31.0	2.6
1007	40	551	456	95.0	2.6
503	20	263	240	23.0	2.6
1002	20	524	478	46.0	2.6
503	15	267	236	31.0	2.6
1003	15	504	473	31.0	2.6
500	40	360	140	220.0	5.6
1004	40	605	399	206.0	5.6
506	20	302	204	98.0	5.6
1001	20	543	457	86.0	5.6
506	15	262	244	18.0	5.6
1001	15	545	456	89.0	5.6

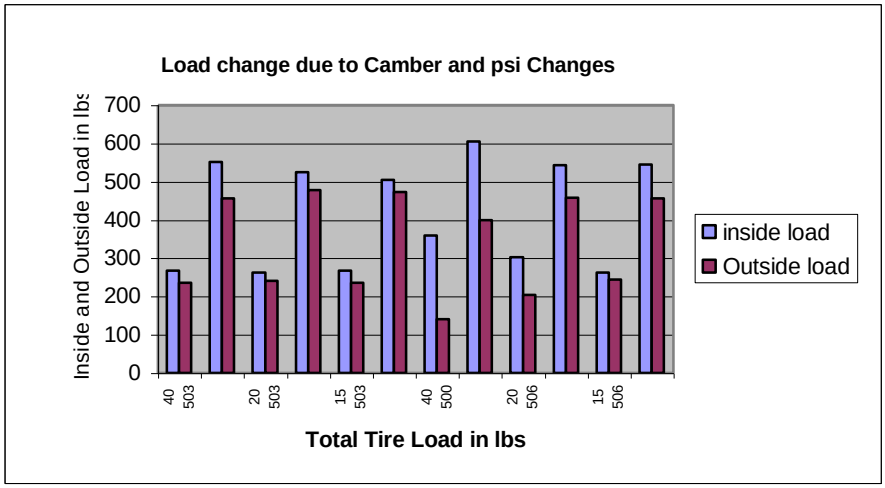


Figure 4-14

Table 4-13 and the graph in Figure 4-15 show changes in the tire's spring rate versus changes in tire pressure during non-dynamic conditions.

Table 4-13

Tire psi vs spring rate__Tire#_ Date			
psi	Load	Change in spring rate lb.	Running Total
26	69	0	/
27	84	15	15
28	99	15	30
29	112	13	43
30	125	13	56
31	138	13	69
32	156	18	87
33	168	12	99
34	186.0	18	117
35	195.0	9	126
36	212.0	17	143
37	225.0	13	156
38	238.0	13	169
39	255.0	17	186
40	266.0	11	197

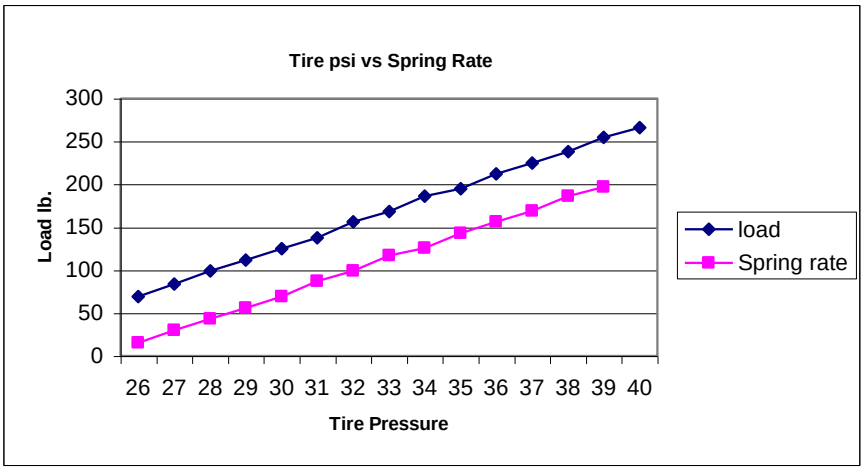


Figure 4-15

Test Data from the Tire Manufacturers

Important Note: Though all of the tables and graphs in this section are **closely representative of actual tire data,** we have, at the same time, been extremely fastidious that no one tire or manufacturer is specifically represented. We have instead combined data from several tires and manufacturers using five separate formulas to make sure no individual would ever be able to relate the data back to any particular tire or manufacturer. In other words, we **don't** want to be sued and we **do want** to keep working as consultants!

In the past number of years, it has become considerably easier for teams to acquire tire data from either the manufacturer or independent test facilities. With the advent of manufacturers of test equipment and facilities such as MTS™, not only are many of the smaller race tire manufacturers able to run extensive test programs but many of the larger race teams are also purchasing their own tire test facilities. In addition, there are more and more private test facilities offering testing for teams who are unable to afford their own equipment. Like wind tunnel and seven poster testing, tire testing by individual teams has become quite common.

Tire Test Data - A single tire test apparatus can measure a multitude of parameters such as steer angle, inclination (camber) angle, loaded radius, normal force, lateral force, longitudinal force, aligning torque, inflation pressure, road speed and drag force to name but a few. Many of the current tire test facilities can provide the client with 100 channels of continuous stream data. Talk about mind boggling amounts of data! We, on the other hand, are only going to look at a few of the most basic data outputs.

Force Versus Load - Table 4-14 and its accompanying graph represent the **primary** tire data table and graph which is *Load versus Cornering Force*. The three tires shown have approximately the same tread width but vastly different aspect ratios, compounding and design characteristics. All other data sets such as camber inclination, psi and steer angle are used to determine the tire's ultimate load versus cornering force performance potential. As discussed in later chapters, it is the tires load versus cornering force numbers that determine a car's mean cornering potential and whether a chassis is balanced or in a loose (oversteer) or push (understeer) condition. For example, for Tire #1, if the LF carried a load of 250 lb. while the RF carried a load of 1750 lb., the chassis' front cornering potential would be (501.8671+953.948)/(250+1750) = 0.728 g. If on the other hand, using the same tire, the LF carried a load of 750 lb. and the RF carried a load of 1250 lb., the chassis' front cornering potential would be (760.0669+884.6459)/(750+1250) = 0.822 g. The difference between 0.728 and 0.822 lateral cornering force for a total front weight of 1500 lb. is 141 lb. When you consider a difference of only 10 lb. between the front and rear can change a balanced chassis to an ill handling chassis, 141 lb. represents a rather large number.

Notice that Tire #3 has a much higher coefficient of friction than Tire #1 but that alone is not the whole story. What this graph does not indicate is that Tire #3 uses a very soft compound which corning force potential will degrade very quickly, particularly if the tread temperature is run at a higher level than the manufacturer's recommended temperature.

Data Table 4-14

Rear - Outside				
Tire#1 - P23-35 Tire #2 - DT3742 Tire #3 - P3538				
Regression Coefficient = 1.277+370.6*SQRT()-34.152*()				
Load	Tire #1	Tire #2	Tire #3	Notes:
250	502	703	1004	
500	659	923	1318	
750	760	1064	1520	
1000	832	1164	1663	
1250	885	1239	1769	
1500	924	1294	1849	
1750	954	1336	1908	
2000	976	1366	1951	
2250	991	1387	1982	
2500	1000	1401	2001	
2750	1006	1408	2011	
3000	1007	1409	2013	

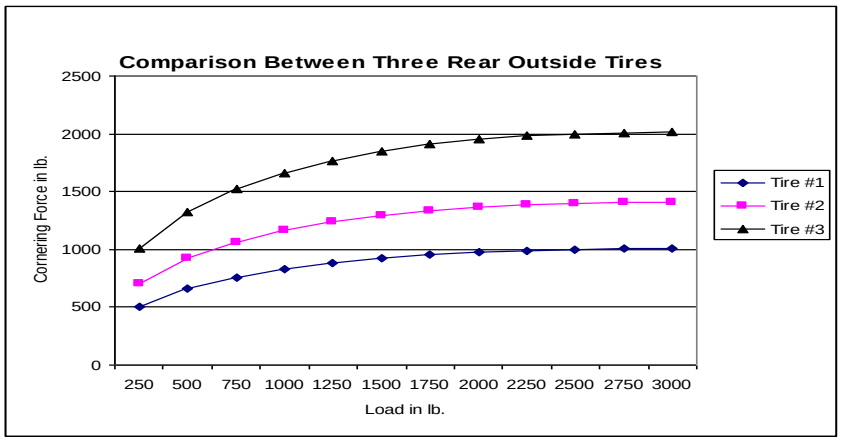


Figure4-16

Data Table 4-15 and its accompanying graph represents cornering forces versus steer angle at three different load levels and 0 degrees of camber. Notice that at 7 degrees of steer angle, the increase in cornering force has become negligible. Also notice that at 7 degrees of steer angle, the data and graph show that the 600 lb. load is less efficient than the 400 lb. load. *Key tuning tool*.

Data Table 4-15

P3235 Front Outside Tire			
LOAD	200 lb.	400 lb.	600 lb.
Steer Angle	0º CAMBER	0º CAMBER	0º CAMBER
0.0	-62	-124	-167
0.5	26	39	30
1.0	110	194	225
1.5	167	312	384
2.0	209	407	522
2.5	250	486	635
3.0	278	551	728
3.5	307	603	804
4.0	328	648	865
4.5	349	689	924
5.0	367	717	969
5.5	383	736	1006
6.0	395	754	1038
6.5	407	765	1059
7.0	413	770	1078

Data Table 4-16

P3235 Front Inside Tire			
LOAD	200 lb.	400 lb.	600 lb.
Steer Angle	0º CAMBER	0º CAMBER	0º CAMBER
0.5	133	252	331
1.0	183	354	468
1.5	225	433	584
2.0	258	502	679
2.5	283	558	755
3.0	309	606	815
3.5	331	644	866
4.0	349	671	908
4.5	364	693	942
5.0	379	710	969
5.5	390	722	995
6.0	401	735	1015
6.5	406	744	1037
7.0	411	750	1049

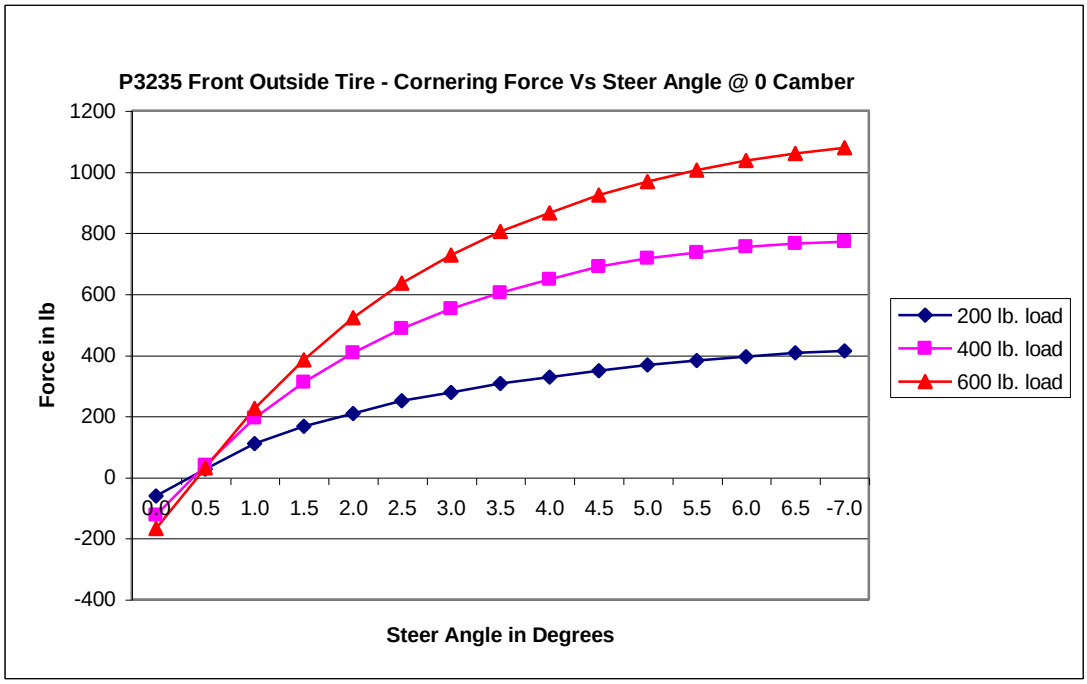


Figure 4-17a (Table 4-15)

Data Table 4-16 and its accompanying graph illustrate the same tire as in the previous example but as an inside tire. Notice the differences between the outside and inside tires even through they are both set at zero camber angle. Up to a steer angle of 2.5, the inside tire, at all loads, produces a higher cornering force than the outside tire. After a steer angle of 3.0, the outside tire produces the higher cornering force. Also remember that a larger steer angle normally equates with a higher heat coefficient.

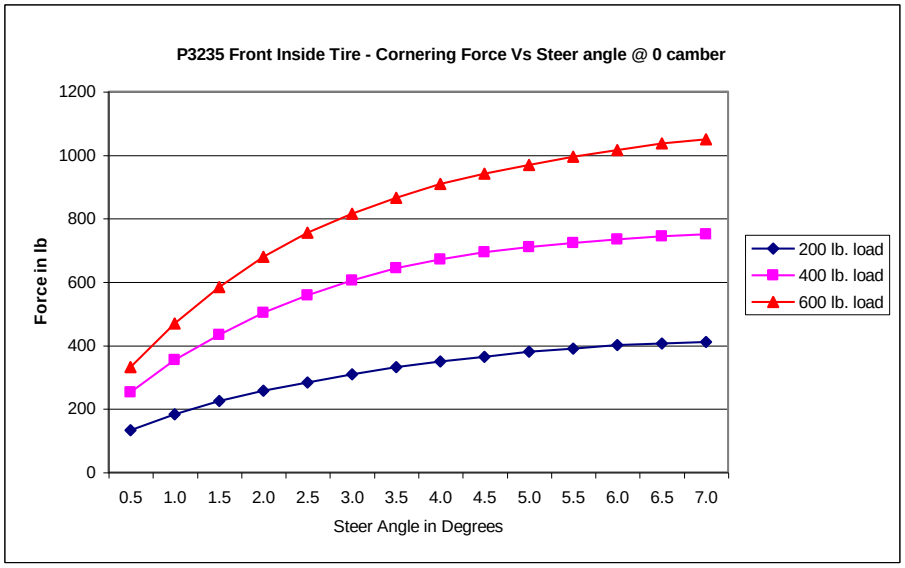


Figure 4-17b (Table 4-16)

Data Tables 4-17 & 4-18 and their accompanying graphs show the difference between the outside and inside tires at -1 degree of camber. The inside tire still produces a higher cornering force up to 2.5 degrees of steer angle, while, after that point, the outside tire produces a higher cornering force than the inside tire. However, the outside tire at -1 degree of camber produces an increasingly higher cornering force than the tire set at 0 degrees of camber while the inside tire set at -1 degree of camber produces a proportionally smaller amount of cornering force than the tire set at 0 degrees of camber. *Key tuning tool.*

Data Table 4-17

P3235 Front Outside Tire							
LOAD	200 lb.	400 lb.	600 lb.	LOAD	200 lb.	400 lb.	600 lb.
Steer Angle	-1° CAMBER	-1° CAMBER	-1° CAMBER	Steer Angle	1° CAMBER	1° CAMBER	1° CAMBER
0.0	-30	-103	-122				
0.5	62	68	74	0.5	105	234	287
1.0	142	228	264	1.0	159	331	424
1.5	201	337	421	1.5	201	413	541
2.0	248	434	554	2.0	238	481	631
2.5	286	509	670	2.5	264	531	706
3.0	316	575	763	3.0	290	575	767
3.5	345	628	838	3.5	312	610	819
4.0	365	677	904	4.0	332	635	860
4.5	385	719	961	4.5	349	656	895
5.0	403	752	1008	5.0	362	674	926
5.5	418	781	1050	5.5	372	689	950
6.0	433	800	1085	6.0	382	701	974
6.5	443	816	1109	6.5	387	713	994
7.0	454	825	1131	7.0	394	722	1010

Data Table 4-18

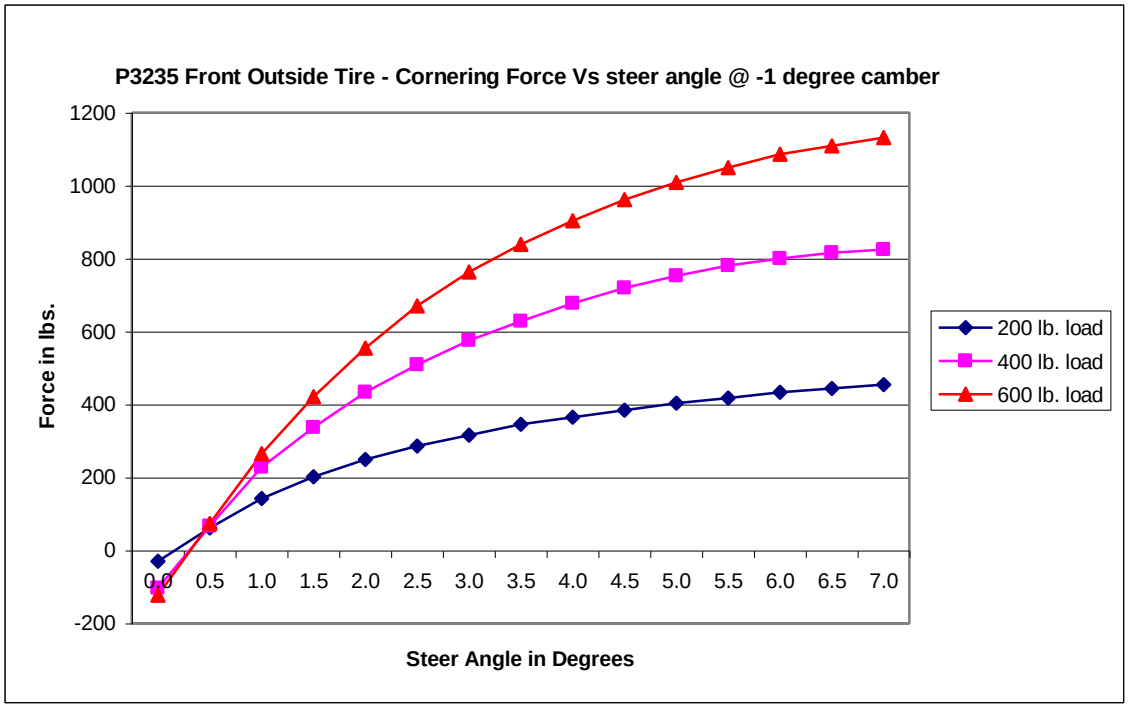


Figure 4-18 (Table 4-17)

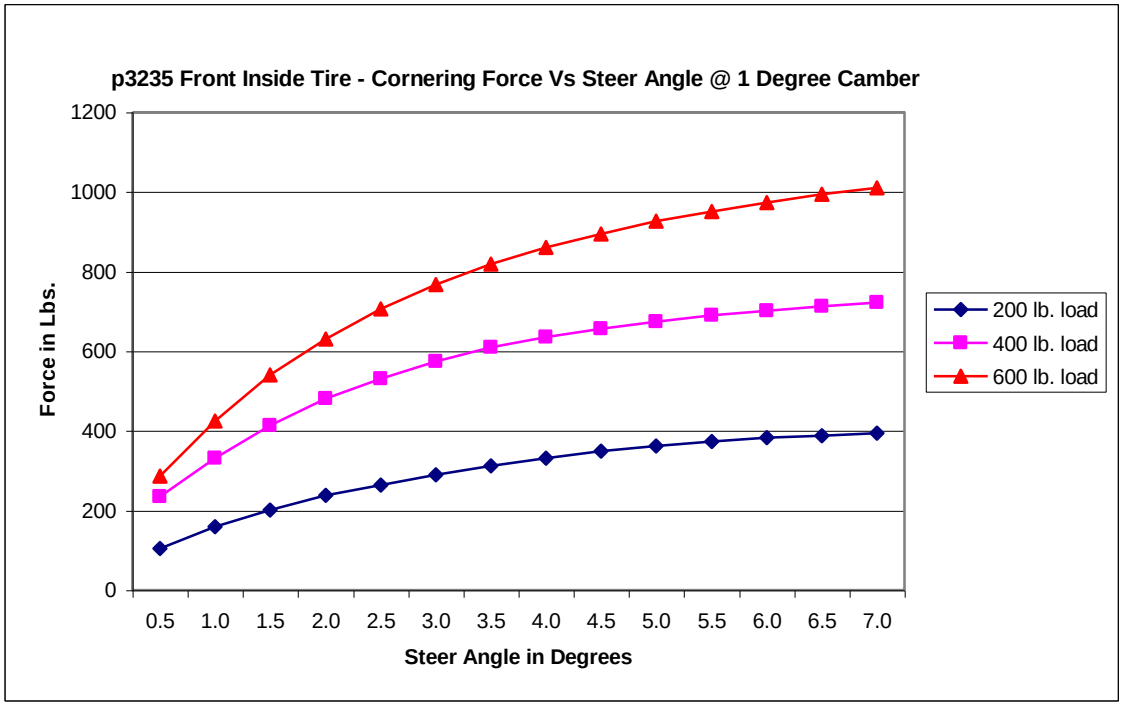


Figure 4-19 (Table 4-18)

As illustrated in data Tables 4-19 & 4-20 and their accompanying graphs, the outside tire set at at -4 degrees of camber produces a much larger cornering force for the same amount of steer angle, than the outside tire set at 0 degrees of camber. The inside tire, on the other hand, set at - 4 degrees of camber produces an increasingly smaller amount of cornering force. Obviously, this is why the inside tires, when running on oval tracks, are set at a positive camber angle.

Data Table 4-19

P3235 Front Outside Tire				**P3235 Front Inside Tire**			
LOAD	200 lb.	400 lb.	600 lb.	LOAD	200 lb.	400 lb.	600 lb.
Steer Angle	-4° CAMBER	-4° CAMBER	-4° CAMBER	Steer Angle	4° CAMBER	4° CAMBER	4° CAMBER
0.0	87	54	35				
0.5	182	211	226	0.5	-10	76	127
1.0	260	345	397	1.0	52	180	261
1.5	318	445	541	1.5	103	267	370
2.0	363	530	660	2.0	146	338	456
2.5	402	599	763	2.5	180	394	528
3.0	433	655	851	3.0	210	441	590
3.5	460	705	927	3.5	234	478	641
4.0	482	753	994	4.0	252	509	684
4.5	503	789	1054	4.5	269	535	723
5.0	518	824	1106	5.0	279	559	756
5.5	534	854	1148	5.5	290	576	786
6.0	546	882	1184	6.0	298	591	810
6.5	555	902	1213	6.5	305	604	828
7.0	564	915	1236	7.0	309	613	846

Data Table 4-20

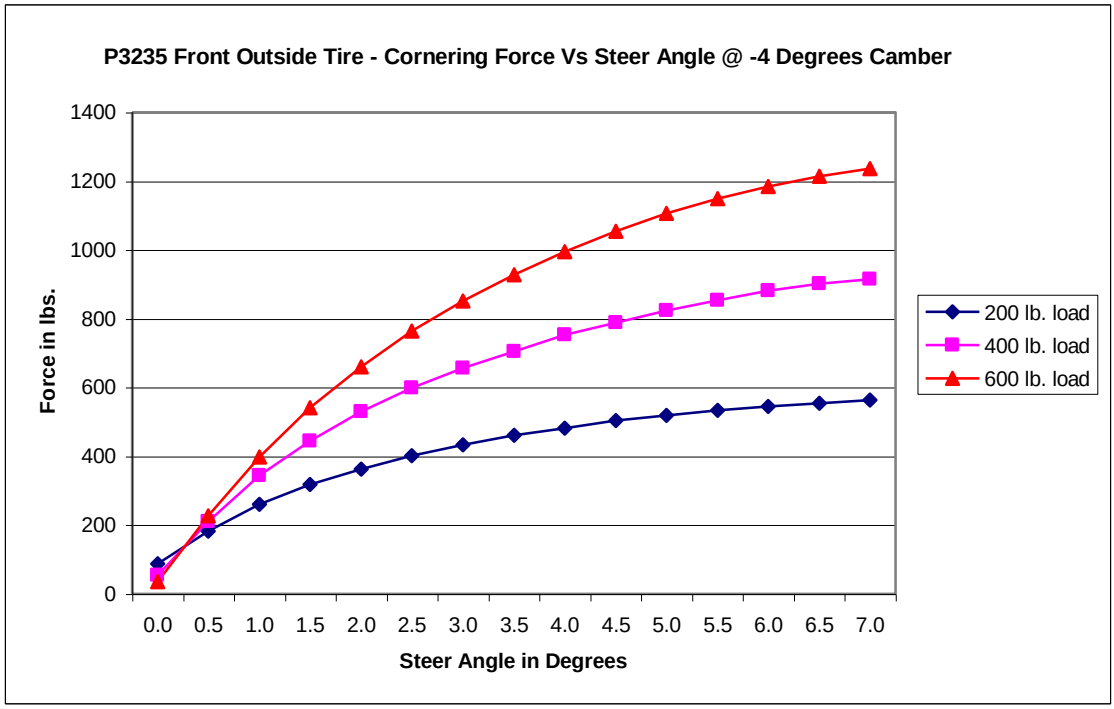


Figure 4-20 (Table 4-19)

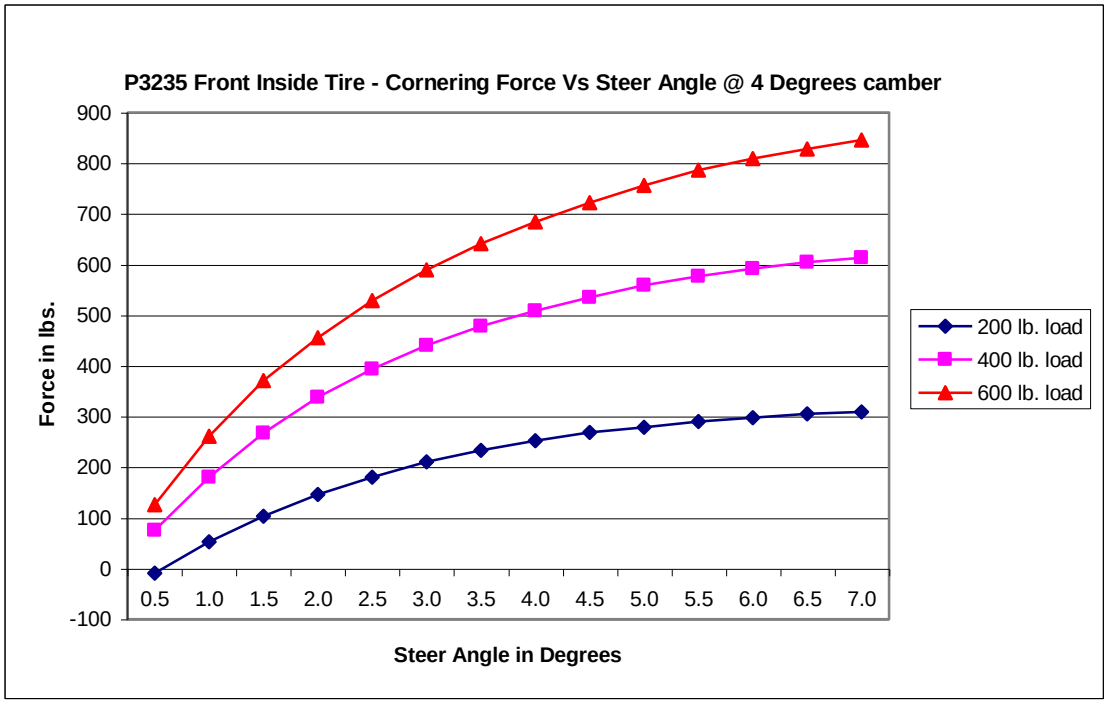


Figure 4-21 (Table 4-20)

Data Tables 4-21 & 4-22 and their accompanying graphs show the outside and inside tires with a load of 600 lb. and varying camber setting from 0 to -4 degrees while the graph in Figure 4-25 combines the same outside and inside tires at 0 and 4 degrees of camber.

Data Table 4-21

P3235 Front Outside Tire					
LOAD	600 lb.	600 lb.	600 lb.	600 lb.	600 lb.
Steer Angle	0º CAMBER	-1º CAMBER	-2º CAMBER	-3º CAMBER	-4º CAMBER
0.0	-167	-122	-69	-14	35
0.5	30	74	129	179	226
1.0	225	264	312	357	397
1.5	384	421	464	506	541
2.0	522	554	594	632	660
2.5	635	670	706	738	763
3.0	728	763	799	829	851
3.5	804	838	879	909	927
4.0	865	904	945	977	994
4.5	924	961	1002	1033	1054
5.0	969	1008	1049	1082	1106
5.5	1006	1050	1091	1123	1148
6.0	1038	1085	1124	1156	1184
6.5	1059	1109	1152	1183	1213
7.0	1078	1131	1177	1209	1236

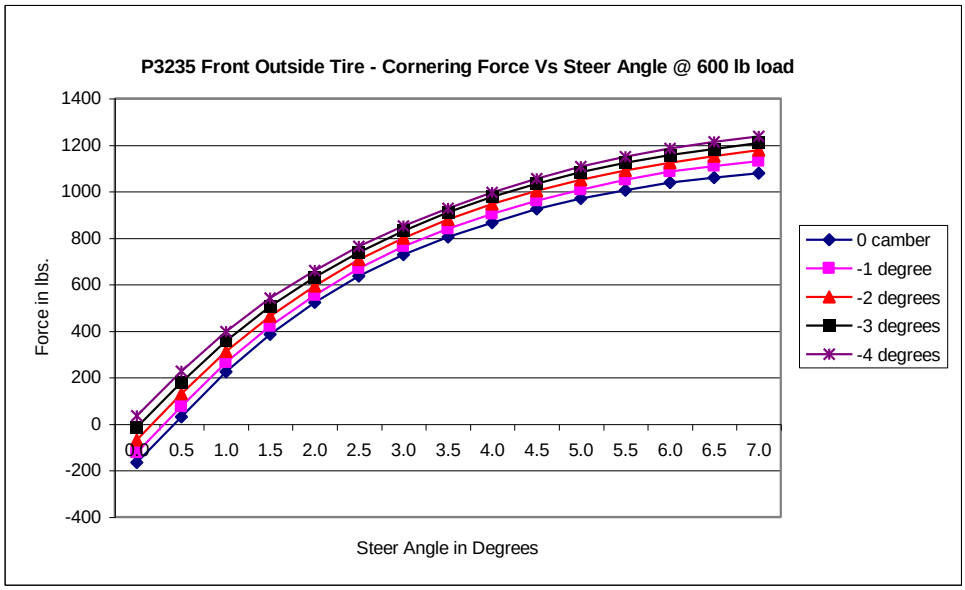


Figure 4-22 (Table 4-21)

Table 4-22

P3235 Front Inside Tire					
LOAD	600 lb.	600 lb.	600 lb.	600 lb.	600 lb.
Steer Angle	0E	-1E	-2E	-3E	-4E
0.5	331	287	233	180	127
1.0	468	424	370	316	261
1.5	584	541	484	430	370
2.0	679	631	574	518	456
2.5	755	706	647	587	528
3.0	815	767	708	649	590
3.5	866	819	758	697	641
4.0	908	860	799	739	684
4.5	942	895	835	776	723
5.0	969	926	866	807	756
5.5	995	950	893	833	786
6.0	1015	974	916	857	810
6.5	1037	994	939	876	828
7.0	1049	1010	953	894	846

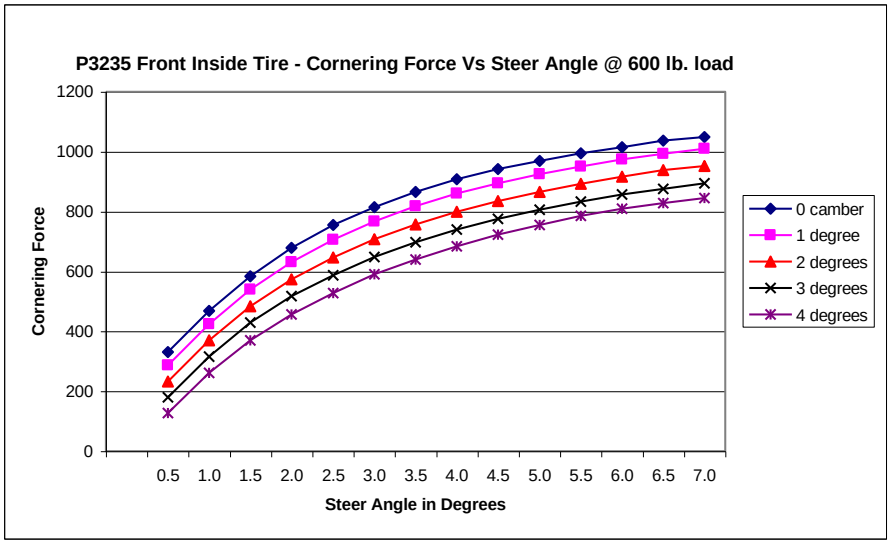


Figure 4-24 (Table 4-22)

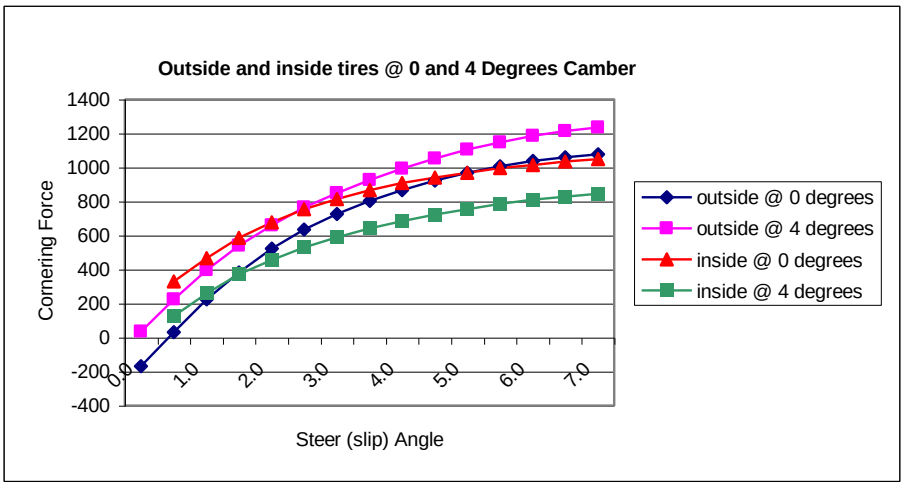


Figure 4-25

Data Table 4-23 and its accompanying graph illustrate the differences in cornering force for a given load between a camber angle of -1 degree and -4 degrees. Notice as the load increases, the tire tested at -4 degrees of camber becomes increasingly efficient. However, this data set does not include longitudinal acceleration efficiencies between the -1 degree and -4 degree tests.

Data Table 4-23

Tire No. P23-35 Rear Outside		
Load	-1 Degree	-4 Degrees
0	0	0
100	335	330
200	534	514
300	700	667
400	849	801
500	986	924
600	1114	1039
700	1235	1147
800	1351	1249
900	1462	1347
1000	1569	1441
1100	1672	1531
1200	1773	1619
1300	1870	1704
1400	1965	1787
1500	2058	1867
1600	2149	1946
1700	2238	2023
1800	2326	2099
1900	2412	2172
2000	2496	2245

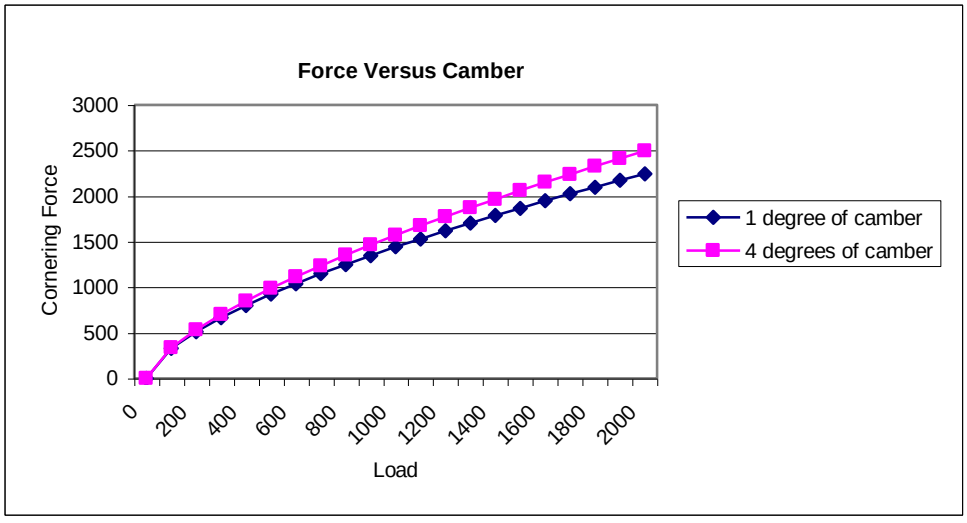


Figure 4-26 (Table 4-23)

Data Tables 4-24 / 4-26 and their accompanying graphs show a tire at 200, 400 and 600 lb. loads with 0, - 2 and - 4 degrees of camber respectively. This is the same tire as in previous examples but from the standpoint of load versus steer angle.

Data Table 4-24

P3235 Front Outside Tire

LOAD	200 lb.	400 lb.	600 lb.
Steer Angle	0E	0E	0E
0.0	-62	-124	-167
0.5	26	39	30
1.0	110	194	225
1.5	167	312	384
2.0	209	407	522
2.5	250	486	635
3.0	278	551	728
3.5	307	603	804
4.0	328	648	865
4.5	349	689	924
5.0	367	717	969
5.5	383	736	1006
6.0	395	754	1038
6.5	407	765	1059
7.0	413	770	1078

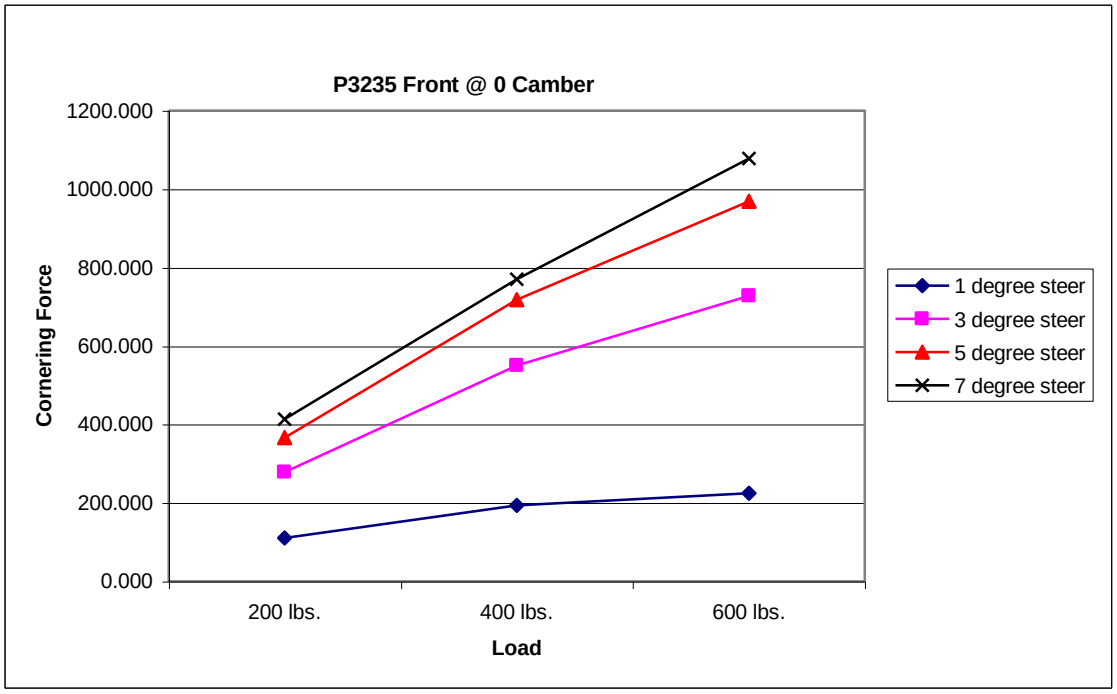


Figure 4-27 (Table 4-24)

Table 4-25

P3235 Front Outside Tire			
LOAD	200 lb.	400 lb.	600 lb.
Steer Angle	-2E Camber	-2E Camber	-2E Camber
0.0	7	-35	-69
0.5	102	124	129
1.0	184	269	312
1.5	242	376	464
2.0	289	466	594
2.5	328	539	706
3.0	359	599	799
3.5	385	654	879
4.0	406	699	945
4.5	428	739	1002
5.0	444	775	1049
5.5	461	807	1091
6.0	473	831	1124
6.5	484	847	1152
7.0	496	860	1177

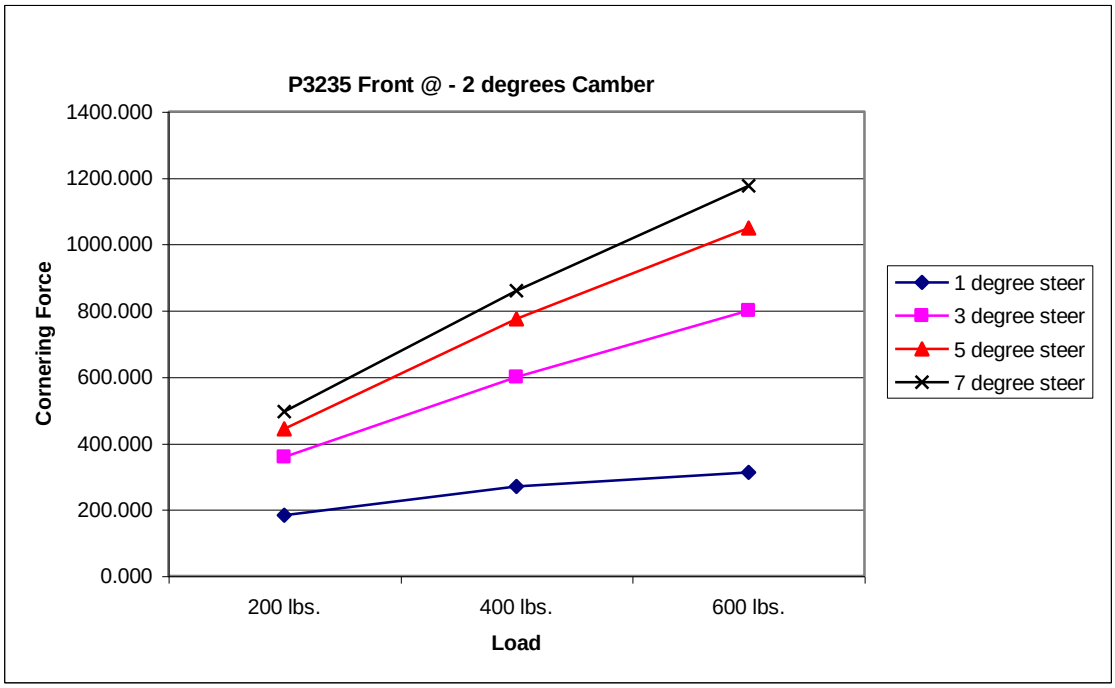


Figure 4-28 (Table 4-25)

Table 4-26

P3235 Front Outside Tire			
LOAD	200 lb.	400 lb.	600 lb.
Steer Angle	-4E Camber	-4E Camber	-4E Camber
0.0	87	54	35
0.5	182	211	226
1.0	260	345	397
1.5	318	445	541
2.0	363	530	660
2.5	402	599	763
3.0	433	655	851
3.5	460	705	927
4.0	482	753	994
4.5	503	789	1054
5.0	518	824	1106
5.5	534	854	1148
6.0	546	882	1184
6.5	555	902	1213
7.0	564	915	1236

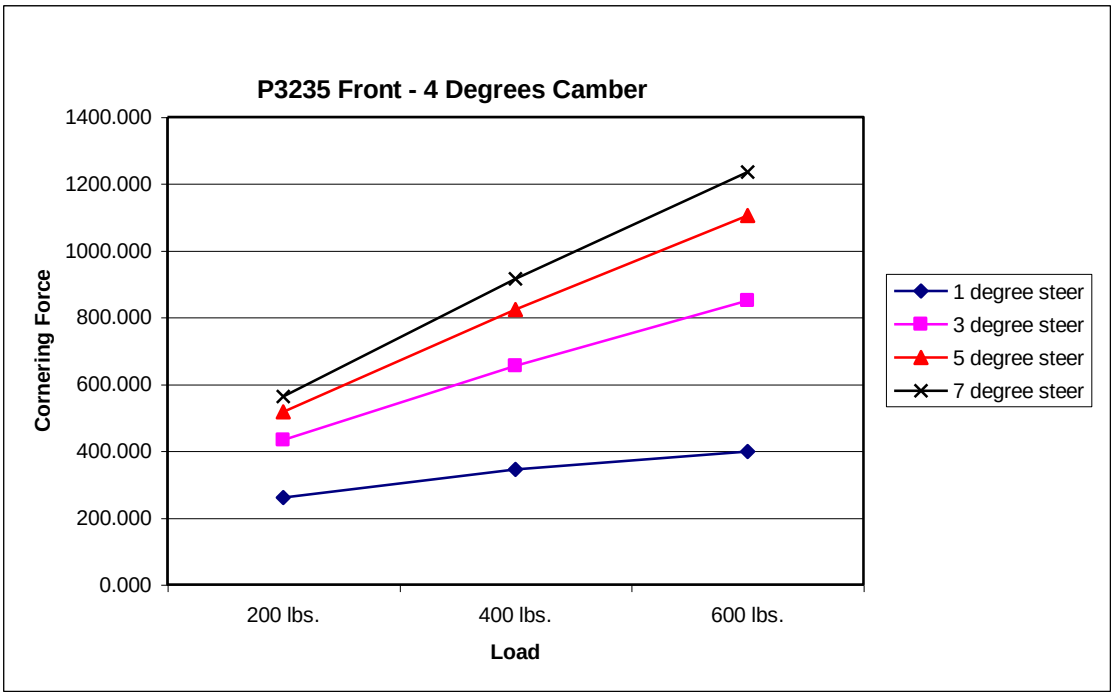


Figure 4-29 (Table 4-26)

Data Tables 4-27 & 4-28 and their accompanying graphs illustrate the difference between two tire designs. Both tires have close to the same tread width but are quite different in their design and compounding. Additionally, Tire P3236 has a larger aspect ratio than Tire DT 14-7-23.

Data Table 4-27

P3236 Outside - Force Versus Camber			
Pressure	24 psi	24 psi	24 psi
LOAD	1200 lb.	1200 lb.	1200 lb.
CAMBER	0E Camber	-2E Camber	-4E Camber
Steer Angle			
0.5	16	138	253
1.0	249	364	468
1.5	460	565	660
2.0	660	755	840
2.5	843	928	1000
3.0	999	1081	1147
3.5	1129	1210	1276
4.0	1242	1320	1385
4.5	1342	1420	1485
5.0	1430	1507	1572
5.5	1508	1582	1648
6.0	1576	1651	1712
6.5	1631	1706	1767
7.0	1673	1753	1810

Data Table 4-28

DT 14-7-23 Outside - Force Vs Camber			
Pressure	24 psi	24 psi	24 psi
LOAD	1200 lb.	1200 lb.	1200 lb.
CAMBER	0E Camber	-2E Camber	-4E Camber
Steer Angle			
0.5	20	183	367
1.0	299	481	679
1.5	552	746	958
2.0	792	997	1218
2.5	1011	1225	1450
3.0	1199	1427	1663
3.5	1354	1597	1850
4.0	1490	1743	2008
4.5	1611	1874	2154
5.0	1717	1989	2280
5.5	1810	2088	2389
6.0	1891	2179	2482
6.5	1957	2252	2562
7.0	2007	2314	2624

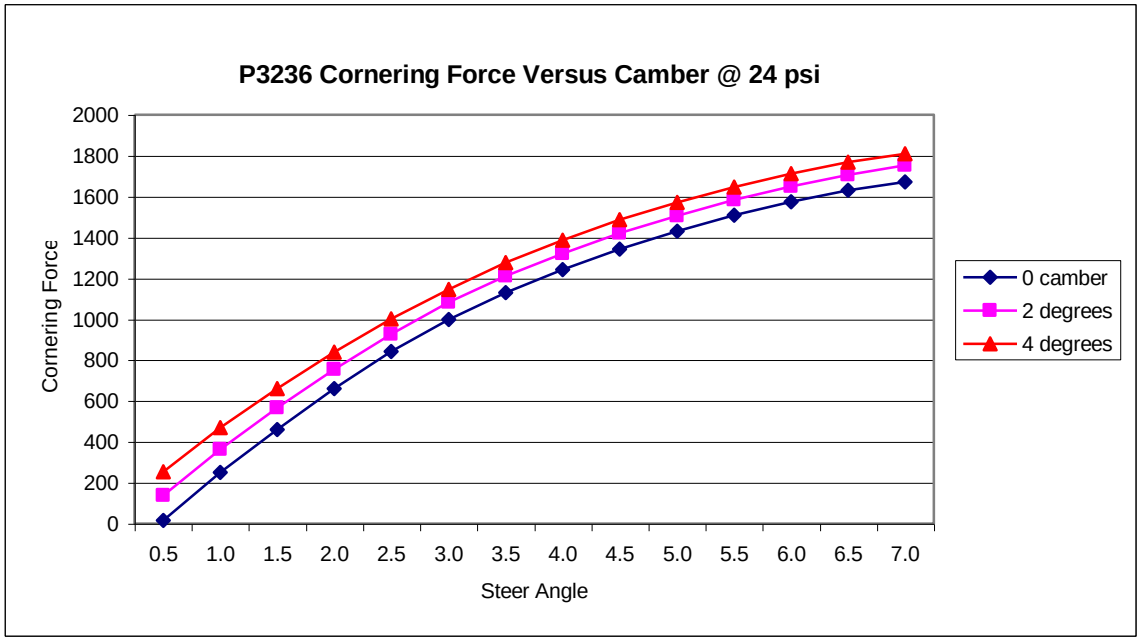


Figure 4-30 (Table 4-26)

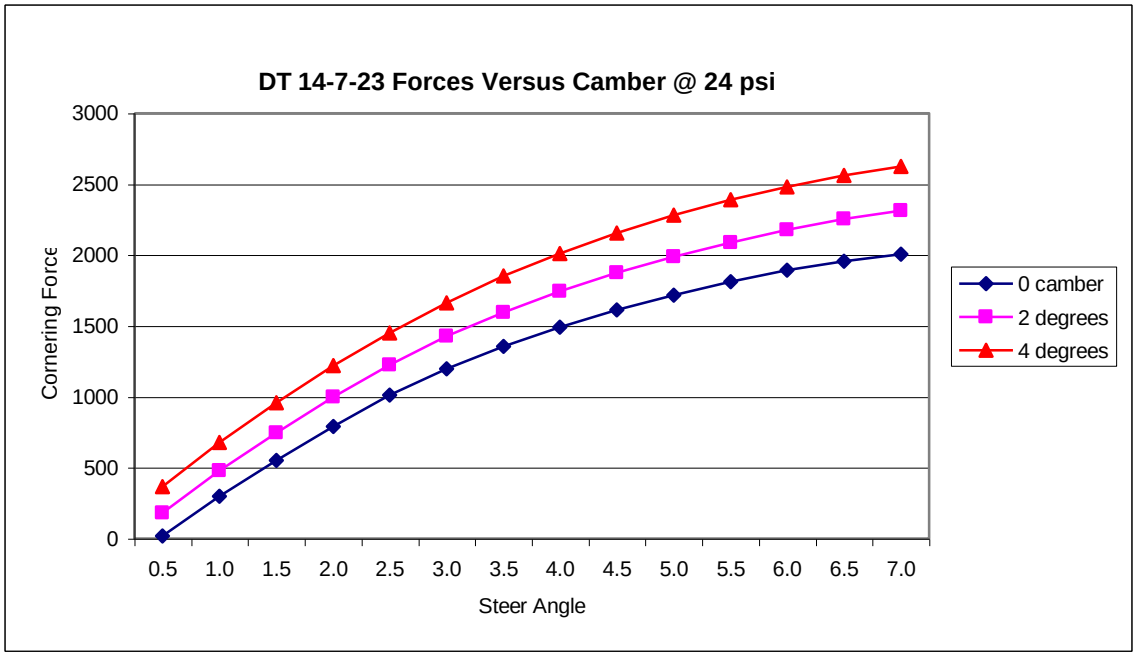


Figure 4-31 (Table 4-28)

Data Table 4-29 and its accompanying graph is the same as in the previous example except it has a tire pressure of 20 psi rather than 24 psi. Data Table 4-30 and its accompanying graph compares the same tire at 1200 lb. and 4 degrees of camber but with a tire pressure of 24 and 20 psi respectively. Notice that Tire DT 14-7-23 at 24 psi produces considerably more force than at 20 psi. As can be seen by this example, lowering the tire pressure to increase the size of the contact patch does not necessarily mean the tire will produce a higher cornering force. Don't take anything for granted. *Key tuning tool*.

Data Table 4-29

DT 14-7-23 Outside - Force Vs Camber			
Pressure	20 psi	20 psi	20 psi
LOAD	1200 lb.	1200 lb.	1200 lb.
CAMBER	-0E	-2E	-4E
Steer Angle			
0.5	17	159	320
1.0	260	418	591
1.5	481	649	833
2.0	689	868	1059
2.5	880	1065	1262
3.0	1043	1242	1447
3.5	1178	1389	1610
4.0	1296	1516	1747
4.5	1401	1630	1874
5.0	1493	1730	1983
5.5	1575	1817	2079
6.0	1645	1895	2159
6.5	1703	1960	2229
7.0	1746	2013	2283

Data Table 4-30

DT 14-7-23 Outside - Force Vs psi		
Pressure	20 psi	24 psi
LOAD	1200 lb.	1200 lb.
CAMBER	-4E	-4º
Steer Angle		
0.5	320	367
1.0	591	679
1.5	833	958
2.0	1059	1218
2.5	1262	1450
3.0	1447	1663
3.5	1610	1850
4.0	1747	2008
4.5	1874	2154
5.0	1983	2280
5.5	2079	2389
6.0	2159	2482
6.5	2229	2562
7.0	2283	2624

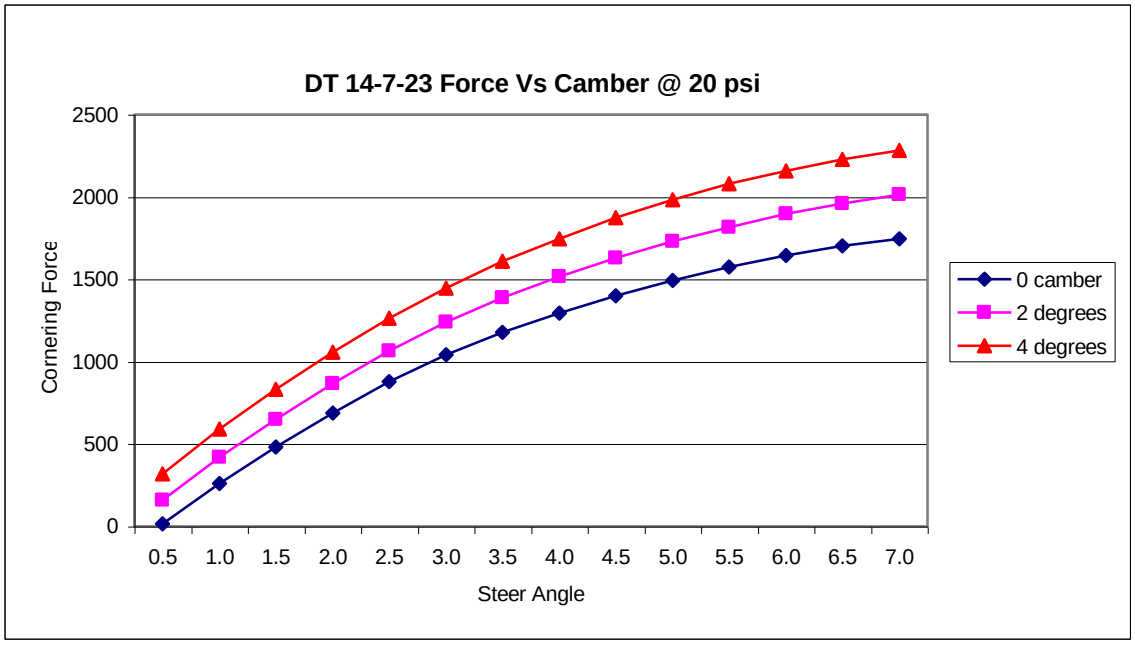


Figure 4-32 (Table 4-29)

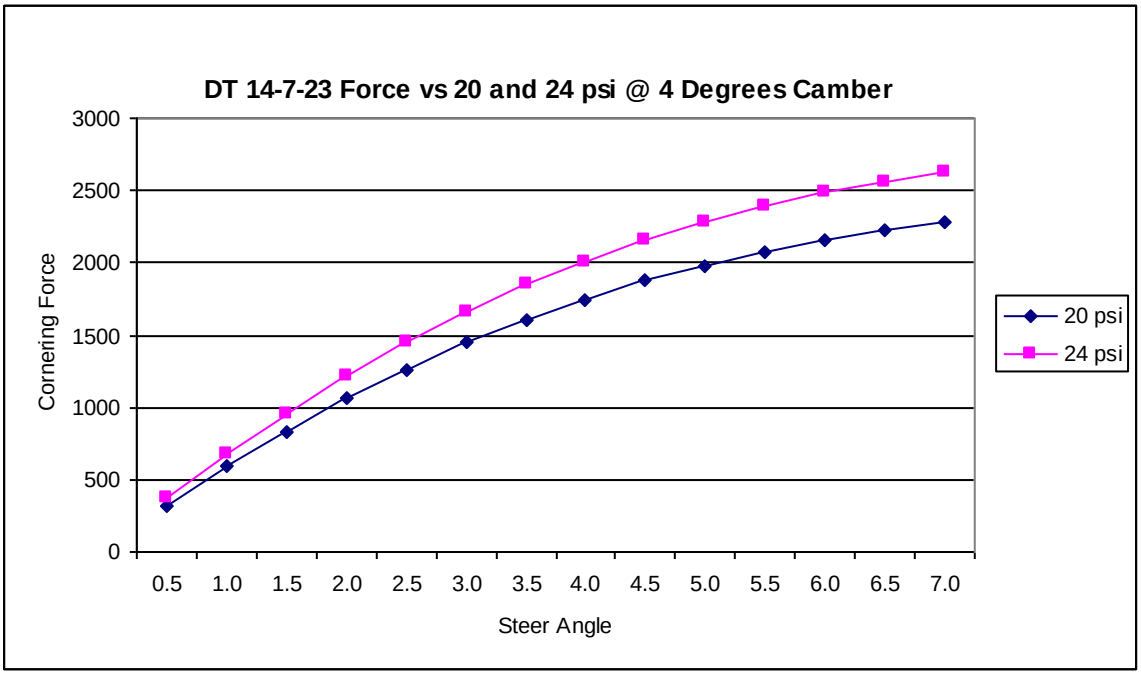


Figure 4-33 (Table 4-30)

Aligning Force/Torque - As discussed in Chapter 3, the force the driver feels at the steering wheel is referred to as aligning torque and it is not that simple to quantify. The torque at the steering wheel is the result of the tires' natural aligning torque combined with moments resulting from kingpin inclination, camber inclination, caster inclination, hub offset, etc.

Even without the various inclination angles and moment arms, the tire has what is referred to as the tire's natural aligning torque. As the elastic forces build up in the tire as a result of being steered (twisted), the tire, in turn, tries to relax those forces (return the forces to zero) by attempting to realign the tire to its straight ahead position. Like everything else in racing, it's just not that simple. The tire's natural aligning torque is affected by inclination angle, dynamic toe, static toe, corner weight, tire pressure, tire temperature, lateral force, longitudinal force, road speed, etc, and, in order to analyze manufacturer's test data, you need to know the various test parameters that have been used to obtain the data. In other words, the pure tire data you get from the tire manufacturer is still only one piece of the puzzle. The chassis' kinematics will often play a greater role in determining steering wheel feedback than the tire's natural aligning torque.

As can be seen in the accompanying graphs, the aligning torque is not always trying to return the tire to the straight ahead position, but, depending on chassis kinematics, may actually be trying to force the tire to steer.

Unlike the raw data presented here, the plots are usually normalized by taking into account the aligning forces at 0 steer angle due to tire asymmetries.

The following graphs are included simply to give the engineer a look at this type of plot. Though important to have access to individual aligning torque information, the combined resultant aligning forces, as measured during dynamic conditions, is what the engineer primarily wants to see. These types of forces can be obtained in a number of ways including strain gauges affixed to the toe links and/or a torque coupler affixed to the steering shaft.

The Importance of Aligning Force/Torque -The absolutely most important numbers regarding aligning torque is where the peak forces (torques) occur in relation to what steer angle a tire's peak lateral acceleration forces occur. Notice that in the accompanying graphs, the peak aligning force/torque occurs in the vicinity of 2 degrees steer angle, while, from the previous graphs, we learned that for the tire tested, the peak lateral acceleration forces are developed at a considerably higher steer angle. If the driver relies on the peak aligning force/torque to determine where the peak lateral forces are, the car will never perform at its potential. This is a big problem for the less talented driver and even the talented driver needs to learn how to feel where, on the declining slope of the aligning torque, the peak lateral acceleration forces occur. *Key tuning tool.*

Having said that, the driver and engineer also need to understand that maximum steer angle is not always what they should be striving for and that instead, the car needs to be set up for a smaller applied steering angle to conserve the tires for longer runs (less heat build up and tire degradation). Teams will want to use the absolute smallest steer angle required to win the race. *Key tuning tool.*

The amount of aligning force the driver feels at the steering wheel can be controlled by the kinematics of the set up and by the power steering settings (where applicable).

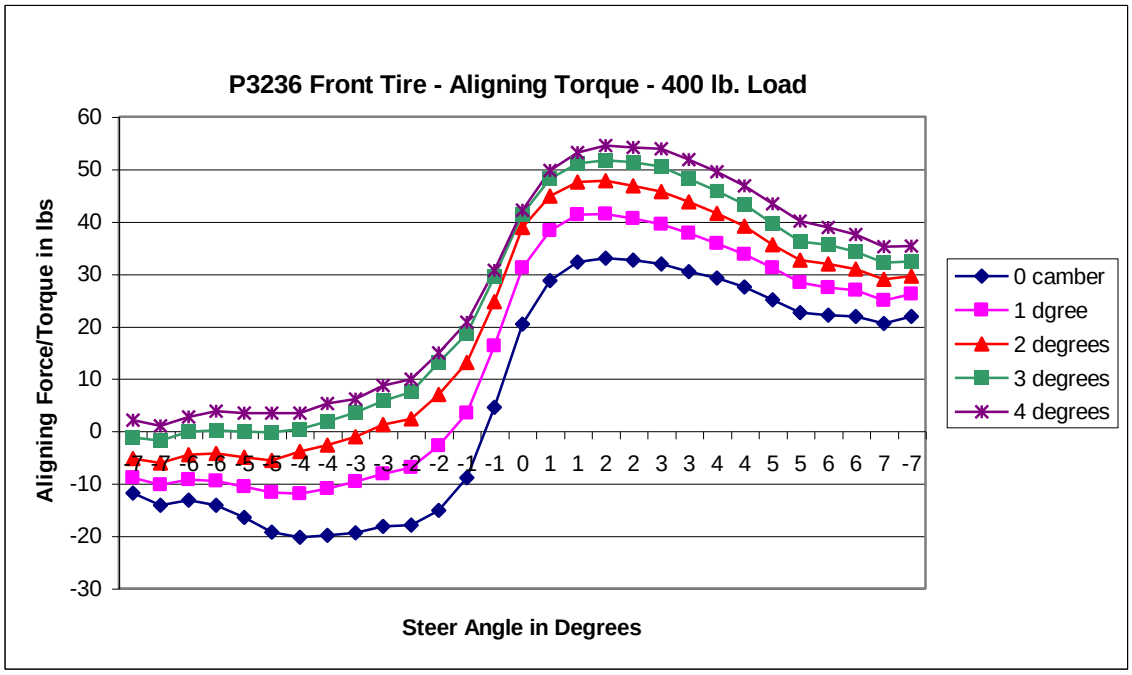


Figure 4-34

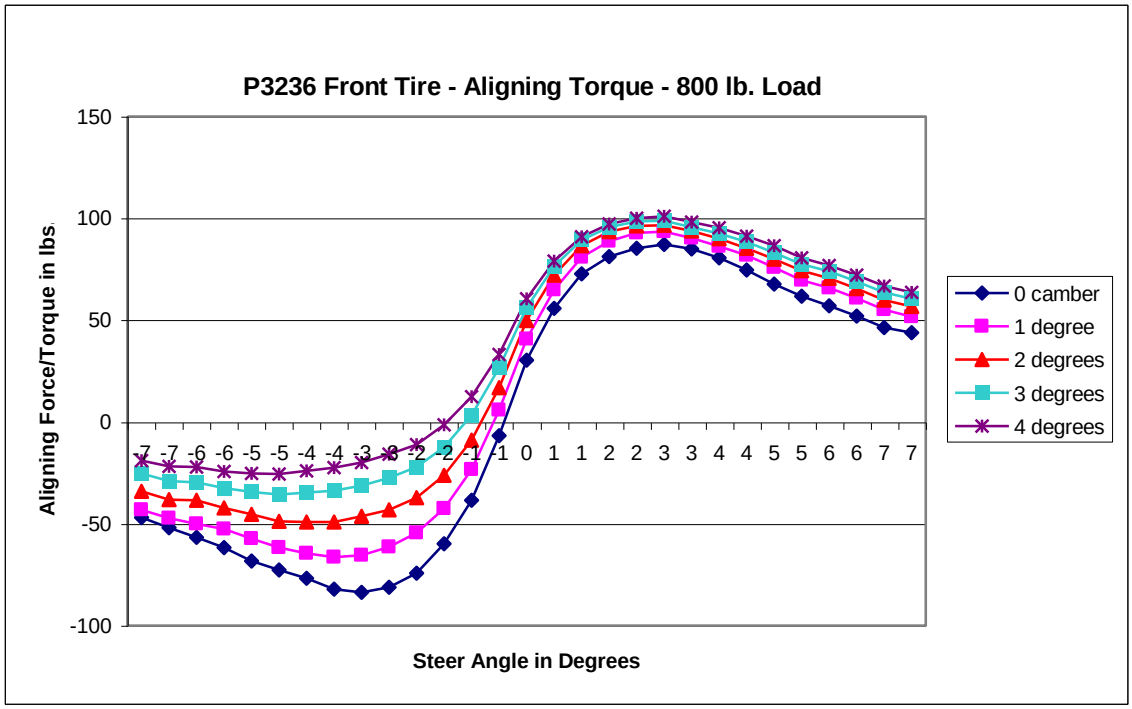


Figure 4-35

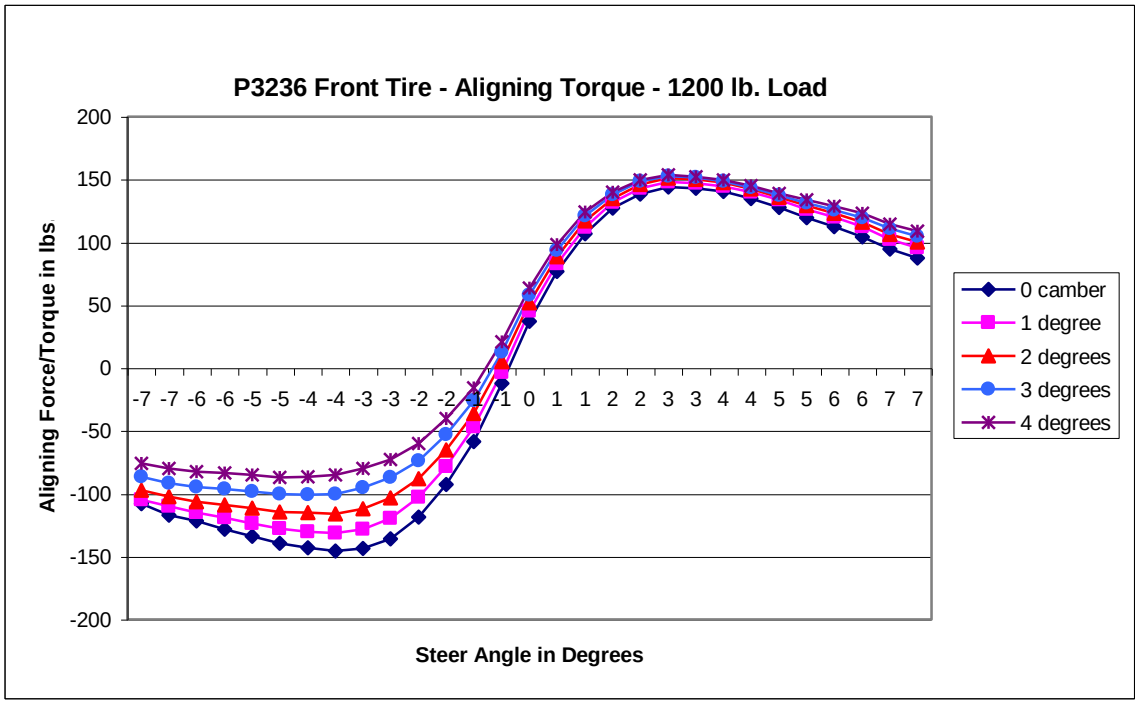


Figure 4-36

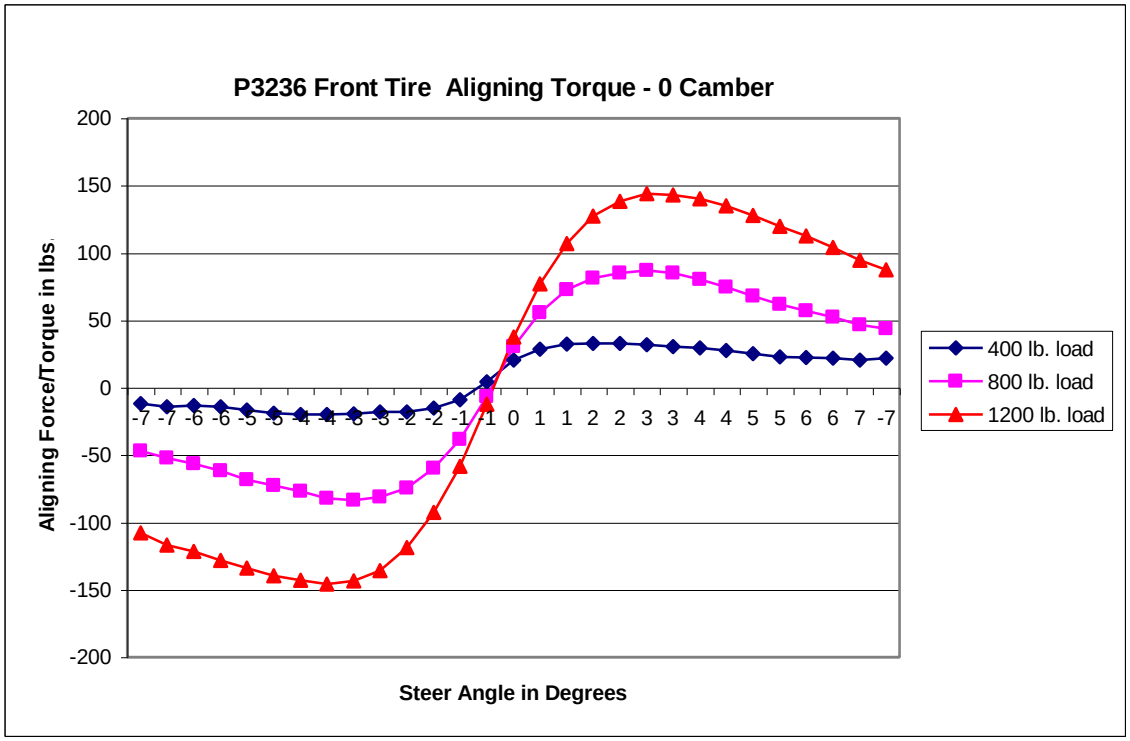


Figure 4-37

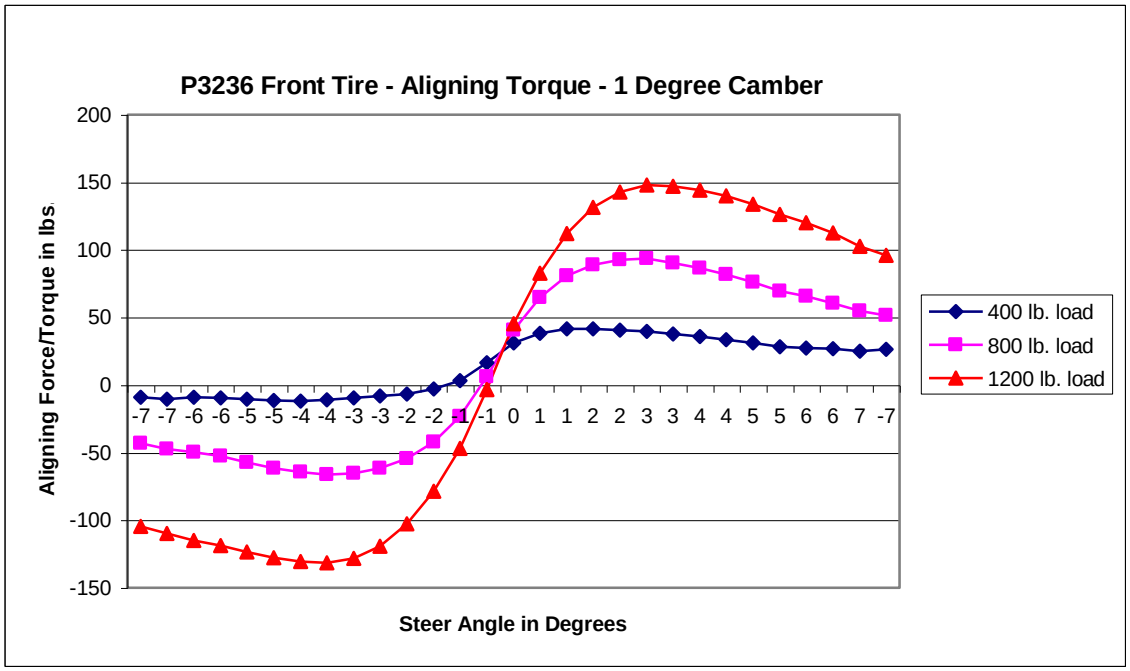


Figure 4-38

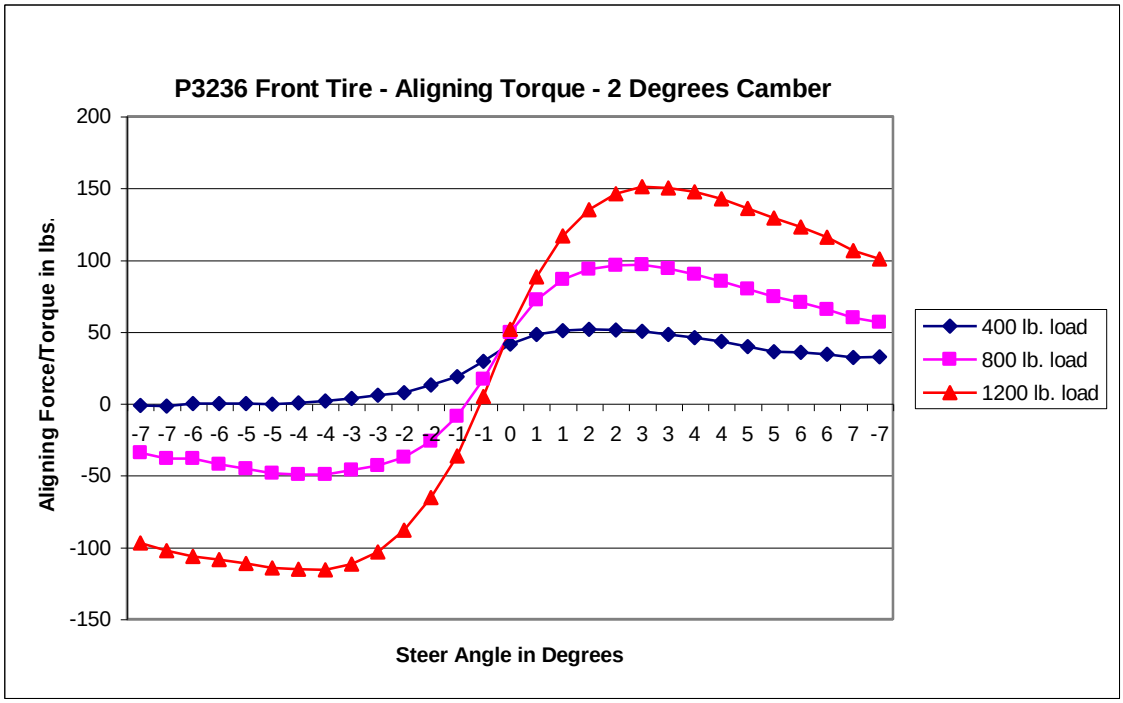


Figure 4-39

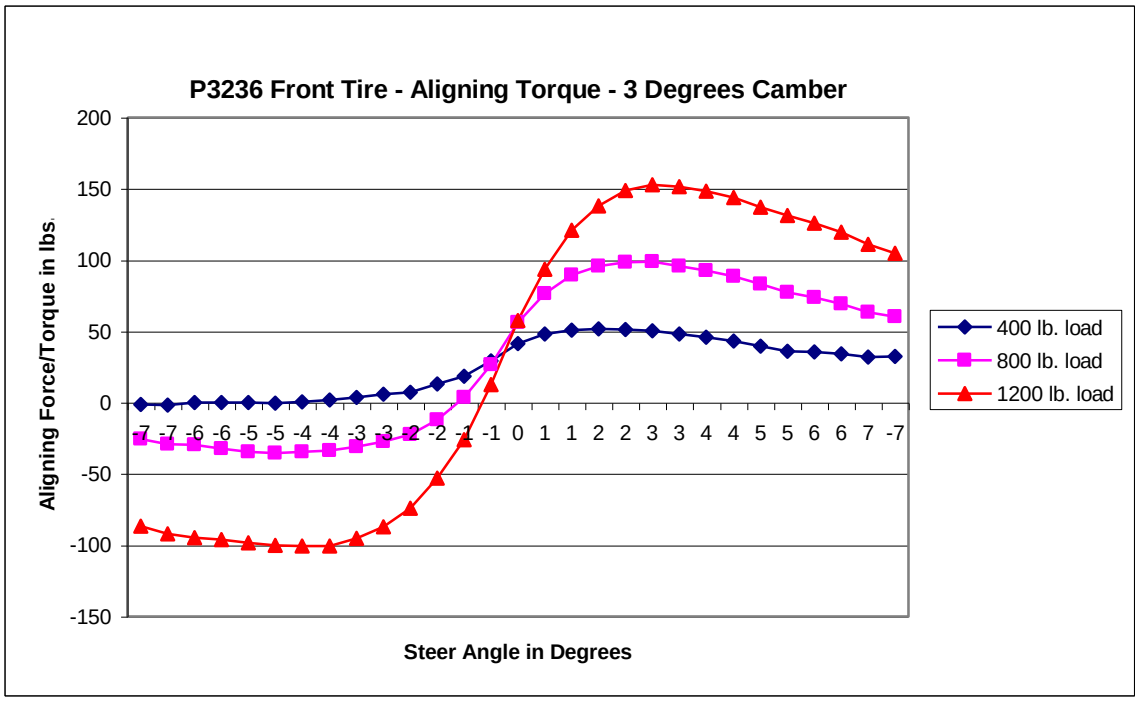


Figure 4-40

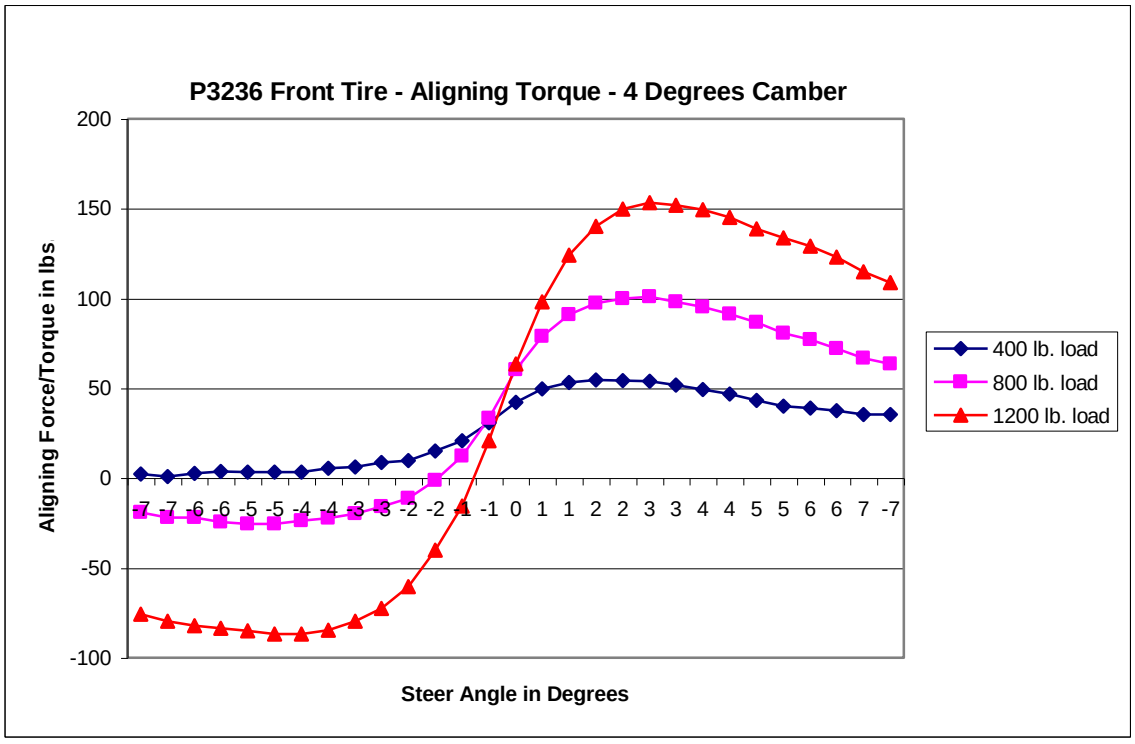


Figure 4-41

Rolling Radius - All pneumatic tires are radius sensitive to load psi changes while not all tires are sensitive to changes in rolling speed. Bias-ply tires are generally the most sensitive to changes in speed while radial tires constructed with steel belts are considerably less sensitive. Whether a tire is sensitive to speed changes or not, the radius changes due to static and dynamic load and psi certainly must be taken into consideration, particularly for aero cars. Flat bottom aero cars running rear diffusers are the most affected by changes in dynamic radius, but, even a stock car running a one mile oval can see its performance characteristics changed dramatically due to changes in tire radius.

Table 4-31 and its accompanying graph show tire radius versus tire load changes at 20 psi. with 0^o, -2^0 and -4^0 Degrees of camber.

Table 4-31

P3235 Front				
Pressure	20 psi	20 psi	20 psi	Contact
Camber	0^o	2^o	4^o	Patch
Load/lb.	Radius/in.	Radius/in.	Radius/in.	Square in.
0	10.59	10.59	10.59	0.00
70	10.55	10.55	10.56	3.50
120	10.53	10.52	10.53	6.00
170	10.49	10.48	10.49	8.50
230	10.44	10.44	10.46	11.50
290	10.39	10.40	10.41	14.50
340	10.35	10.35	10.35	17.00
400	10.30	10.29	10.30	20.00
460	10.25	10.24	10.24	23.00
520	10.19	10.18	10.19	26.00
575	10.14	10.15	10.14	28.75
630	10.08	10.08	10.07	31.50
690	10.05	10.03	10.02	34.50
750	10.00	9.98	9.96	37.50
800	9.95	9.93	9.91	40.00
859	9.90	9.88	9.86	42.95
920	9.86	9.83	9.81	46.00
980	9.81	9.79	9.75	49.00
1030	9.76	9.74	9.70	51.50
Total Change	0.83	0.85	0.89	

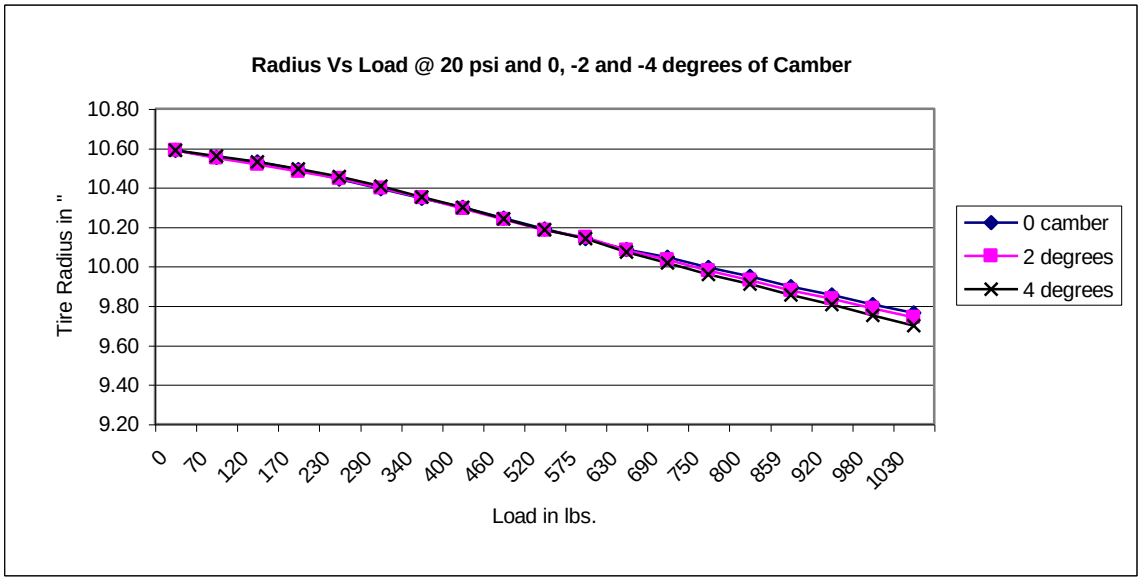


Figure 4-42

Table 4-32 and its accompanying graph shows tire radius versus tire load changes at 22 psi. with 0^{o}, -2^{0} and -4^{0} Degrees of camber.

Table 4-32

P3235 Front					
Pressure	22 psi	22 psi	22 psi	Contact	Patch
Camber	0^{o}	2^{o}	4^{o}	Patch	Change
Load/lb.	Radius/in.	Radius/in.	Radius/in.	Square in.	From 20 psi
0	10.59	10.59	10.59	0.00	0.00
70	10.54	10.55	10.55	3.18	0.32
120	10.52	10.52	10.54	5.45	0.55
170	10.49	10.48	10.51	7.73	0.77
230	10.43	10.45	10.47	10.45	1.05
290	10.39	10.40	10.42	13.18	1.32
340	10.35	10.36	10.37	15.45	1.55
400	10.30	10.30	10.31	18.18	1.82
460	10.25	10.25	10.27	20.91	2.09
520	10.20	10.21	10.21	23.64	2.36
575	10.15	10.16	10.16	26.14	2.61
630	10.11	10.12	10.12	28.64	2.86
690	10.08	10.06	10.06	31.36	3.14
750	10.02	10.02	10.00	34.09	3.41
800	9.98	9.97	9.95	36.36	3.64
859	9.93	9.92	9.92	39.05	3.90
920	9.90	9.87	9.86	41.82	4.18
980	9.85	9.84	9.81	44.55	4.45
1030	9.80	9.78	9.76	46.82	4.68
Total Change	0.7927	0.8096	0.8306		

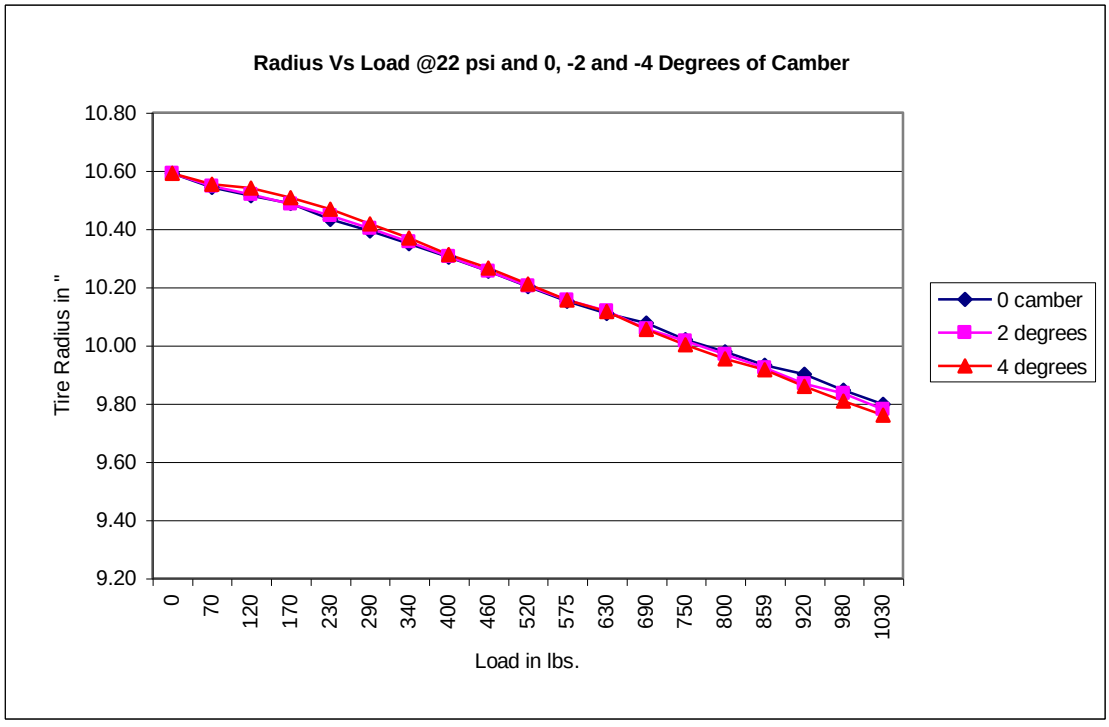


Figure 4-43

Figures 4-44 & 4-45 illustrate the change in radius due to changes in rotation speed for two different tires. Figure 4-44 is a radial tire and Figure 4-45 is a bias-ply tire. Each tire design, whether radial or bias-ply construction, will have its own radius versus mph factors. The radial tire shows a radius increase of 0.076" while the bias ply tire shows a radius increase of 0.359".

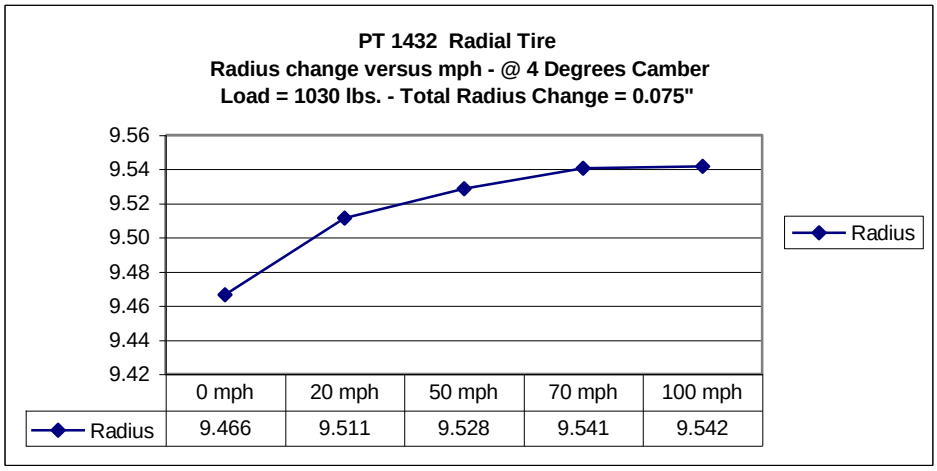


Figure 4-44

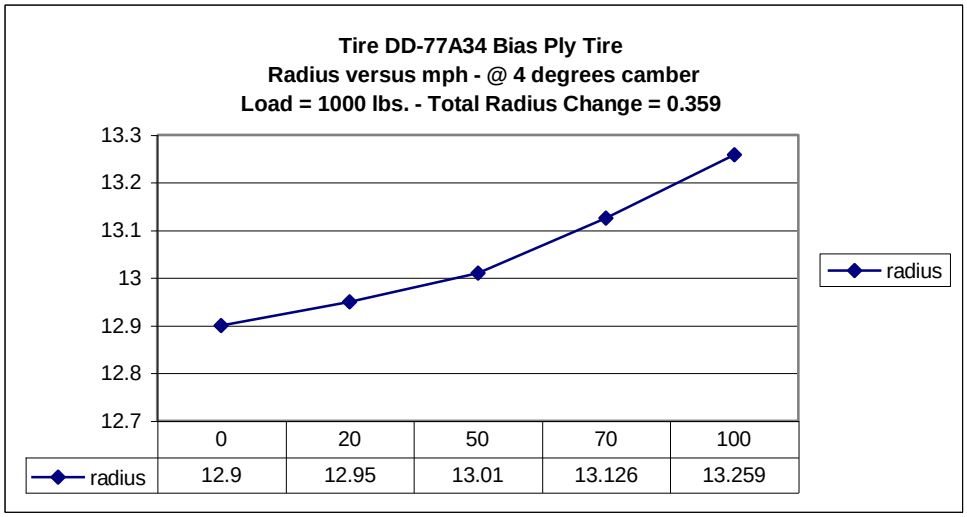


Figure 4-45